SNS-104010000-DC0001-R00

# DESIGN CRITERIA DOCUMENT

## WBS 1.4.1

## Linac RF System

Date: November 30, 2000

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# Linac RF System


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# Los Alamos National Laboratory
# Spallation Neutron Source

## Linac RF System
## Design Criteria Document

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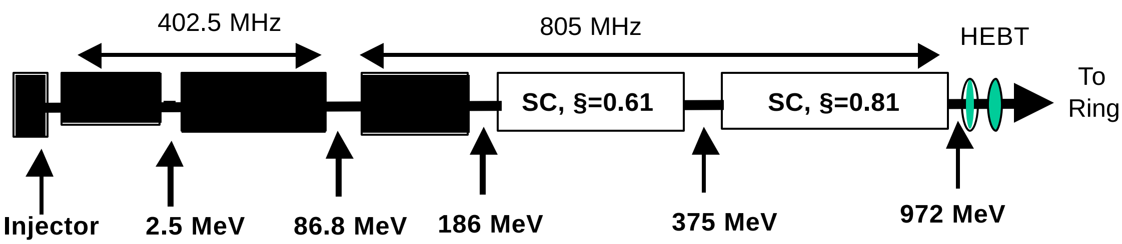
# SNS Linac RF System Design Criteria Document (DCD)
# November-30-2000

## Outline



## System Description




The different structures and frequencies require that 3 different types of klystrons be used. The RFQ and DTL will use 2.5 MW peak klystrons at 402.5 MHz. The CCL will use 5 MW peak klystrons at 805 MHz, and the superconducting cavities will use 550 kW klystrons at 805 MHz. The types and quantities and applications are listed in Table 1.

Table 1: Types and quantities of klystrons and HV systems for the SNS Linac

| | |
|---|---|
| $H^-$ Energy | 972 MeV |
| Average beam during pulse | 36 mA |
| Pulse Width | 1 ms |
| Rep Rate | 60 Hz |
| Klystrons<br>402.5 MHz, 2.5 MW pk<br>*(includes 1 for RFQ , 6 for DTL)*<br>805 MHz, 5 MW pk<br>*(includes 4 for CCL, 2 for HEBT)*<br>805 MHz, 0.55 MW pk, SC | <br>7<br><br>6<br><br>92 |
| HV Converter/Modulators<br>(16 Total) | 1 for each 5 MW klystron or pair of 2.5 MW klystrons (except 1 for RFQ and first 2 DTL's & 1 for 2 HEBT cavities)<br>1 for 11 or 12 0.55 MW klystrons |

# Main Body

## 1. System Parameters affecting the Linac RF Design

| | |
|---|---|
| Pulse Rep Rate | 60 Hz |
| Nominal pulse width | 1 ms |
| Average linac current during pulse | 35 mA |
| Number of RFQ/DTL 402.5 MHz klystrons | 7 |
| Number of CCL 5 MW klystrons | 4 |
| Number of SC 550 kW klystrons | 92 |
| Number of HEBT klystrons | 2 |
| Amplitude Control, each system, nominal | ±0.5% |
| Amplitude Control, each system, disable pulse | ±0.75% |
| Phase control, each system, nominal | ±0.5° |
| Phase control, each system, disable pulse | ±0.75° |
| Excess power margin, minimal design level, 402.5 MHz | 25% [power margin = (cavity power + beam power)*1.25] |
| Excess control power, minimal design level, 805 MHz CCL and SRF | 33% [power margin = (cavity power + beam power)*1.33] |

The power needed in each cavity when compared to the available klystron power determines the amount of excess power available for controls. The power margin is calculated as the power available above the beam power plus cavity power, divided by the beam power plus cavity power. Table 2 lists the maximum available power margin (if the klystron were set up to provide full rated power) for each cavity and the minimum excess power needed for controls. The SRF cavity powers include the reflective losses which come from using fixed coupling in the medium and high beta cavities. Optimal coupling would require a different coupling setting for each cavity. The numbers do not consider errors in coupling, current level, etc. Those errors are absorbed in the excess power level. The CCL margin is listed at 33% because of the split the CCL waveguide makes and because of the extremely high power level of these klystrons. The excess margin will perhaps allow us to avoid running these klystrons flat-out.

**Table 2.** Power needed in each cavity, the excess power available, and the minimum excess power needed for controls.

| Structure | Structure power (kW) | Beam Power (kW) | Total Power (kW) | Klystron Power (kW) | Maximum Available Power Margin (%) | Minimum margin for RF controls |
|---|---|---|---|---|---|---|
| RFQ | 630 | 130 | 760 | 2500 | 229% | 25% |
| DTL-1 | 342 | 178 | 520 | 2500 | 381% | 25% |
| DTL-2 | 1047 | 553 | 1600 | 2500 | 56% | 25% |
| DTL-3 | 1320 | 610 | 1930 | 2500 | 30% | 25% |
| DTL-4 | 1326 | 604 | 1930 | 2500 | 30% | 25% |
| DTL-5 | 1297 | 573 | 1870 | 2500 | 34% | 25% |
| DTL-6 | 1364 | 516 | 1880 | 2500 | 33% | 25% |
| CCL-1 | 2127 | 691 | 2818 | 5000 | 77% | 33% |
| CCL-2 | 2465 | 815 | 3280 | 5000 | 52% | 33% |
| CCL-3 | 2493 | 887 | 3380 | 5000 | 48% | 33% |
| CCL-4 | 2530 | 966 | 3496 | 5000 | 43% | 33% |

| | | | | | | |
|---|---|---|---|---|---|---|
| SRF-1 | 0 | 165 | 165 | 550 | 234% | 33% |
| SRF-2 | 0 | 171 | 171 | 550 | 222% | 33% |
| SRF-3 | 0 | 177 | 177 | 550 | 211% | 33% |
| SRF-4 | 0 | 183 | 183 | 550 | 201% | 33% |
| SRF-5 | 0 | 188 | 188 | 550 | 192% | 33% |
| SRF-6 | 0 | 194 | 194 | 550 | 184% | 33% |
| SRF-7 | 0 | 199 | 199 | 550 | 177% | 33% |
| SRF-8 | 0 | 203 | 203 | 550 | 171% | 33% |
| SRF-9 | 0 | 208 | 208 | 550 | 165% | 33% |
| SRF-10 | 0 | 211 | 211 | 550 | 160% | 33% |
| SRF-11 | 0 | 215 | 215 | 550 | 156% | 33% |
| SRF-12 | 0 | 218 | 218 | 550 | 153% | 33% |
| SRF-13 | 0 | 220 | 220 | 550 | 150% | 33% |
| SRF-14 | 0 | 222 | 222 | 550 | 148% | 33% |
| SRF-15 | 0 | 224 | 224 | 550 | 146% | 33% |
| SRF-16 | 0 | 225 | 225 | 550 | 145% | 33% |
| SRF-17 | 0 | 226 | 226 | 550 | 144% | 33% |
| SRF-18 | 0 | 226 | 226 | 550 | 143% | 33% |
| SRF-19 | 0 | 226 | 226 | 550 | 143% | 33% |
| SRF-20 | 0 | 226 | 226 | 550 | 144% | 33% |
| SRF-21 | 0 | 225 | 225 | 550 | 144% | 33% |
| SRF-22 | 0 | 224 | 224 | 550 | 145% | 33% |
| SRF-23 | 0 | 224 | 224 | 550 | 146% | 33% |
| SRF-24 | 0 | 223 | 223 | 550 | 147% | 33% |
| SRF-25 | 0 | 221 | 221 | 550 | 148% | 33% |
| SRF-26 | 0 | 220 | 220 | 550 | 150% | 33% |
| SRF-27 | 0 | 219 | 219 | 550 | 152% | 33% |
| SRF-28 | 0 | 217 | 217 | 550 | 154% | 33% |
| SRF-29 | 0 | 215 | 215 | 550 | 156% | 33% |
| SRF-30 | 0 | 213 | 213 | 550 | 158% | 33% |
| SRF-31 | 0 | 211 | 211 | 550 | 160% | 33% |
| SRF-32 | 0 | 209 | 209 | 550 | 163% | 33% |
| SRF-33 | 0 | 207 | 207 | 550 | 165% | 33% |
| SRF-34 | 0 | 239 | 239 | 550 | 130% | 33% |
| SRF-35 | 0 | 245 | 245 | 550 | 124% | 33% |
| SRF-36 | 0 | 251 | 251 | 550 | 119% | 33% |
| SRF-37 | 0 | 257 | 257 | 550 | 114% | 33% |
| SRF-38 | 0 | 263 | 263 | 550 | 109% | 33% |
| SRF-39 | 0 | 269 | 269 | 550 | 104% | 33% |
| SRF-40 | 0 | 275 | 275 | 550 | 100% | 33% |
| SRF-41 | 0 | 281 | 281 | 550 | 95% | 33% |
| SRF-42 | 0 | 288 | 288 | 550 | 91% | 33% |
| SRF-43 | 0 | 294 | 294 | 550 | 87% | 33% |
| SRF-44 | 0 | 300 | 300 | 550 | 83% | 33% |
| SRF-45 | 0 | 306 | 306 | 550 | 80% | 33% |
| SRF-46 | 0 | 312 | 312 | 550 | 76% | 33% |

| | | | | | | |
|---|---|---|---|---|---|---|
| SRF-47 | 0 | 317 | 317 | 550 | 73% | 33% |
| SRF-48 | 0 | 323 | 323 | 550 | 70% | 33% |
| SRF-49 | 0 | 329 | 329 | 550 | 67% | 33% |
| SRF-50 | 0 | 334 | 334 | 550 | 65% | 33% |
| SRF-51 | 0 | 339 | 339 | 550 | 62% | 33% |
| SRF-52 | 0 | 344 | 344 | 550 | 60% | 33% |
| SRF-53 | 0 | 349 | 349 | 550 | 58% | 33% |
| SRF-54 | 0 | 354 | 354 | 550 | 55% | 33% |
| SRF-55 | 0 | 358 | 358 | 550 | 53% | 33% |
| SRF-56 | 0 | 363 | 363 | 550 | 52% | 33% |
| SRF-57 | 0 | 367 | 367 | 550 | 50% | 33% |
| SRF-58 | 0 | 371 | 371 | 550 | 48% | 33% |
| SRF-59 | 0 | 374 | 374 | 550 | 47% | 33% |
| SRF-60 | 0 | 378 | 378 | 550 | 46% | 33% |
| SRF-61 | 0 | 381 | 381 | 550 | 44% | 33% |
| SRF-62 | 0 | 384 | 384 | 550 | 43% | 33% |
| SRF-63 | 0 | 387 | 387 | 550 | 42% | 33% |
| SRF-64 | 0 | 390 | 390 | 550 | 41% | 33% |
| SRF-65 | 0 | 393 | 393 | 550 | 40% | 33% |
| SRF-66 | 0 | 395 | 395 | 550 | 39% | 33% |
| SRF-67 | 0 | 397 | 397 | 550 | 38% | 33% |
| SRF-68 | 0 | 399 | 399 | 550 | 38% | 33% |
| SRF-69 | 0 | 401 | 401 | 550 | 37% | 33% |
| SRF-70 | 0 | 403 | 403 | 550 | 37% | 33% |
| SRF-71 | 0 | 404 | 404 | 550 | 36% | 33% |
| SRF-72 | 0 | 406 | 406 | 550 | 36% | 33% |
| SRF-73 | 0 | 407 | 407 | 550 | 35% | 33% |
| SRF-74 | 0 | 408 | 408 | 550 | 35% | 33% |
| SRF-75 | 0 | 409 | 409 | 550 | 34% | 33% |
| SRF-76 | 0 | 410 | 410 | 550 | 34% | 33% |
| SRF-77 | 0 | 411 | 411 | 550 | 34% | 33% |
| SRF-78 | 0 | 412 | 412 | 550 | 34% | 33% |
| SRF-79 | 0 | 412 | 412 | 550 | 33% | 33% |
| SRF-80 | 0 | 413 | 413 | 550 | 33% | 33% |
| SRF-81 | 0 | 413 | 413 | 550 | 33% | 33% |
| SRF-82 | 0 | 413 | 413 | 550 | 33% | 33% |
| SRF-83 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-84 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-85 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-86 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-87 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-88 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-89 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-90 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-91 | 0 | 414 | 414 | 550 | 33% | 33% |
| SRF-92 | 0 | 413 | 413 | 550 | 33% | 33% |

# 2. High power RF design parameters

### *2.1. System Level*

| | |
|---|---|
| 402.5 MHz Klystrons per transmitter | 1 |
| 805 MHz, 5 MW klystrons per transmitter | 1 |
| 805 MHz, 550 kW klystrons per transmitter | 6, max |
| Circulators | yes, for all klystrons |
| Splitting of klystron output | only the CCL klystrons (split once) |

### *2.2. Component Parameters, by item*

#### *2.2.1. SNS 402.5 MHz, 2.5 MW, Klystrons Specification*

| | |
|---|---|
| RF Operating Frequency | 402.5 MHz |
| Peak Output Power | 2.5 MW, minimum |
| RF Duty Factor | 8% |
| Pulse Repetition Rate | 60 Hz |
| DC to RF Efficiency | 58% minimum at rated power. |
| Beam Voltage | 130 kV, Maximum |
| Beam Current | 35 A, Maximum |
| RF Power Gain | 45 dB, Minimum |
| Instantaneous Bandwidth | ± 1.0 MHz 1 dB Minimum Bandwidth at Saturation. ± 0.7 MHz 1 dB Minimum Bandwidth at 80% of saturated output power. |

#### *2.2.2. SNS 805 MHz, 5.0 MW, Klystrons Specification*

| | |
|---|---|
| RF Operating Frequency | 805.0 MHz |
| Peak Output Power | 5.0 MW, minimum |
| RF Duty Factor | 9% |
| Pulse Repetition Rate | 60 Hz |
| DC to RF Efficiency | 55% minimum at rated power. |
| Beam Voltage | 140 kV, Maximum |
| Beam Current | 88. A, Maximum |
| RF Power Gain | 50 dB, Minimum |
| Instantaneous Bandwidth | ± 1.3 MHz 1 dB Minimum Bandwidth at Saturation. ± 1.0 MHz 1 dB Minimum Bandwidth at 80% of saturated output power. |

#### *2.2.3. SNS 805 MHz, 550 kW, Klystrons Specification*

| | |
|---|---|
| RF Operating Frequency | 805.0 MHz |
| Peak Output Power | 0.55 MW, minimum |
| RF Duty Factor | 9% |
| Pulse Repetition Rate | 60 Hz |
| DC to RF Efficiency | 65%, minimum at rated power. |
| Beam Voltage | 75 kV, ± 1.5 kV |

| | |
|---|---|
| Beam Current | 11.3 A Nominal, 11.5 A Maximum |
| RF Power Gain | 50 dB, Minimum |
| Instantaneous Bandwidth | ± 1.3 MHz 1 dB Minimum Bandwidth at Saturation.<br>± 1.0 MHz 1 dB Minimum Bandwidth at 80% of saturated output power. |

### ***2.2.4. SNS 402.5 MHz, 2.5 MW, Circulator Specification***

***General***

This specification describes the requirements for the 402.5 MHz Y-junction circulator. The circulator shall protect a 2.5 MW peak-power klystron amplifier from reflected power. The pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 8%, and a corresponding maximum pulse width of 1.3 ms.

***Performance Specifications***

**Center Frequency**

The center frequency shall be 402.5 MHz.

**Forward Power**

The maximum forward peak power shall be 2.5 MW with the worst case pulse format described in Section 1.0 above into a fully reflective load at arbitrary phase. Into a load with a maximum VSWR of 2:1 (11% reflected power), the forward power shall be as high as 2.75 MW**.**

**Reverse Power**

The maximum reverse peak power at any phase shall be equal to the maximum forward peak power and pulse format.

**Insertion Loss**

The insertion loss at center frequency at all forward power levels shall be less than 0.07 dB. The insertion loss at the center frequency ± 6 MHz shall be less than 0.17 dB.

**Isolation**

The isolation at center frequency shall be =26 dB. The isolation at the center frequency ± 0.5 MHz shall be =20 dB. The isolation at the center frequency ± 6 MHz shall be =10 dB.

**Return Loss**

The input and output VSWR at center frequency shall be less than 1.05:1. The input and output VSWR at center frequency ± 6 MHz shall be less than 1.2:1.

### ***2.2.5. SNS 805 MHz, 5.0 MW, Circulator Specification***

***General***

This specification describes the requirements for an 805 MHz Y-junction circulator. The circulator shall protect a 5.0 MW peak-power klystron amplifier from reflected power. The forward pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 9%, and a corresponding maximum pulse width of 1.5 msec.

*Performance Specifications*

**Center Frequency**

The center frequency shall be 805 MHz.

**Forward Power**

The maximum forward peak power shall be 5.0 MW with the worst case pulse format described in Section 1.0 above into a fully reflective load at arbitrary phase. Into a load with a maximum VSWR of 2:1 (11% reflected power), the forward power shall be as high as 5.5 MW.

**Reverse Power**

The maximum reverse peak power at any phase shall be equal to the maximum forward peak power of 5.0 MW at a 9% duty.

**Insertion Loss**

The insertion loss at center frequency at all forward power levels shall be less than 0.07 dB. The insertion loss at the center frequency ± 12 MHz shall be less than 0.17 dB.

**Isolation**

The isolation at center frequency shall be =26 dB. The isolation at the center frequency ± 2 MHz shall be =20 dB. The isolation at the center frequency ± 12 MHz shall be =10 dB.

**Return Loss**

The input and output VSWR at center frequency shall be less than 1.05:1. The input and output VSWR at center frequency ± 12 MHz shall be less than 1.2:1.

### 2.2.6. SNS 805 MHz, 550 kW, Circulator Specification

*General*

This specification describes the requirements for an 805 MHz Y-junction circulator. The circulator shall protect a 550 kW peak-power klystron amplifier from reflected power. The pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 9%, and a corresponding maximum pulse width of 1.5 ms.

*Performance Specifications*

**Center Frequency**

The center frequency shall be 805 MHz.

**Forward Power**

The maximum forward peak power shall be 550 kW with the worst case pulse format described in Section 1.0 above into a fully reflective load at arbitrary phase. Into a load with a maximum VSWR of 2:1 (11% reflected power), the forward power shall be as high as 610 kW. The forward power shall also be 1.1 MW at a worst case pulse format of 4.5% duty factor, maximum pulse repetition frequency of 60 Hz, and a corresponding maximum pulse width of 0.75 ms into a fully reflective load at arbitrary phase.

Note, this half-duty factor requirement is intended as a testable requirement to insure that the circulator is designed to handle the peak transient fields that have been experienced by accelerators driving super conducting cavities. Analysis and experience has shown that under some circumstances driving a super conducting cavity can result in a short duration transient standing wave with the peak E and H fields equal to 9 times the nominal traveling wave field when the circulator has ports 2 and 3 terminated in a matched load.

**Reverse Power**

The maximum reverse peak power at any phase shall be equal to the maximum forward peak power of 550 kW at a 9% duty factor and 1.1 MW at a 4.5% duty factor as described in sections 1.0 and 2.2.

**Insertion Loss**

The insertion loss at center frequency at all forward power levels shall be less than 0.07 dB. The insertion loss at the center frequency ± 12 MHz shall be less than 0.17 dB.

**Isolation**

The isolation at the center frequency shall be =26 dB with ports 2 and 3 of the circulator connected to a high-power load, supplied by the university, with a VSWR of 1.05:1 or better. The isolation at the center frequency ± 2 MHz shall be =20 dB. The isolation at the center frequency ± 12 MHz shall be =10 dB.

**Return Loss**

The input and output VSWR at center frequency shall be less than 1.05:1 with ports 2 and 3 of the circulator connected to a high-power load, supplied by the university, with a VSWR of 1.05:1 or better. The input and output VSWR at center frequency ± 12 MHz shall be less than 1.2:1.

### *2.2.7. SNS 402.5 MHz, DTL RF Window Specification*

This specification is for a RF vacuum window through which power shall be provided to an accelerating cavity by a klystron amplifier.

***Center Frequency***

The center frequency for the window shall be 402.5 MHz.

***Bandwidth***

The bandwidth shall be at least 7 MHz centered at 402.5 MHz. All requirements of this specification shall be satisfied over this frequency band except as otherwise noted.

***Typical Operation***

The typical operating forward power through the window shall be 2.5 MW peak and 200 kW average.

***Acceptance Tests (to be performed by Los Alamos National Laboratory)***

The high power acceptance tests will be divided into two tests: peak power and average power. The window shall meet all performance and reliability requirements at the following two conditions:

**Peak Power**

The window shall pass 10 MW peak at 100 µs pulses, 120 Hz and 120 kW average for 4 hours.

**Average power**

The windows shall pass 300 kW average power for 4 hours.

### *2.2.8. SNS 805 MHz, CCL Window Specification*

This specification is for a RF vacuum window through which power shall be provided to an accelerating cavity by a klystron amplifier.

***Center Frequency***

The center frequency for the window shall be 805 MHz.

***Bandwidth***

The bandwidth shall be at least 14 MHz centered at 805 MHz. All requirements of this specification shall be satisfied over this frequency band except as otherwise noted.

***Typical Operation***

The typical operating forward power through the window shall be 2.5 MW peak and 200 kW average.

***Acceptance Tests (to be performed by Los Alamos National Laboratory)***

The high power acceptance tests will be divided into two tests: peak power and average power. The window shall meet all performance and reliability requirements at the following two conditions:

**Peak Power**

The window shall pass 10 MW peak at 100 μs pulses, 120 Hz and 120 kW average for 4 hours.

**Average power**

The windows shall pass 300 kW average power for 4 hours.

### *2.2.9. SNS 402.5 MHz, 2.5 MW, Load Specification*

***General***

This specification describes the requirements for the 402.5 MHz load. The load shall be used as a test load for a klystron, or as the absorptive load on a circulator. The pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 9%, and a corresponding maximum pulse width of 1.5 ms.

***Performance Specifications***

All performance specifications shall be met for the full range of inlet and outlet cooling temperatures defined in this specification.

**Center Frequency**

The center frequency shall be 402.5 MHz.

**Forward Power**

The maximum peak power that the load shall absorb is 2.5 MW with the worst case pulse format described in Section 1.0 above.

**Bandwidth**

Except as otherwise noted the load shall meet all requirements of this specification over ± 6 MHz centered at the center frequency.

**VSWR**

For all conditions described in this specification the VSWR of the load shall be less than 1.07:1 over ± 0.5 MHz centered at the center frequency and less than 1.15:1 over ± 6 MHz centered at the center frequency.

### 2.2.10. SNS 805 MHz, 5.0 MW, Load Specification

***General***

This specification describes the requirements for the 805 MHz load. The load shall be used as a test load for a klystron, as the absorptive load on a circulator, or as the absorptive load on a hybrid splitter. The pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 8%, and a corresponding maximum pulse width of 1.3 ms.

***Performance Specifications***

All performance specifications shall be met for the full range of inlet and outlet cooling temperatures defined in this specification.

**Center Frequency**

The center frequency shall be 805 MHz.

**Forward Power**

The maximum peak power that the load shall absorb is 5.0 MW with the worst case pulse format described in Section 1.0 above with the flow rate of =80 gpm of water. The load shall meet all performance specifications at 2.0 MW with the worst case pulse format described in Section 1.0 above with the flow rate of =40 gpm of water.

**Bandwidth**

Except as otherwise noted the load shall meet all requirements of this specification over ± 12 MHz centered at the center frequency.

**VSWR**

For all conditions described in this specification the VSWR of the load shall be less than 1.07:1 over ± 1.0 MHz centered at the center frequency and less than 1.15:1 over ± 12 MHz centered at the center frequency.

### 2.2.11. SNS 805 MHz, 600 kW, Load Specification

***General***

This specification describes the requirements for the 805 MHz load. The load shall be used as a test load for a klystron or as the absorptive load on a circulator. The pulsed RF will have a maximum pulse repetition frequency of 60 Hz, a maximum duty factor of 10%, and a corresponding maximum pulse width of 1.6 ms.

***Performance Specifications***

All performance specifications shall be met for the full range of inlet and outlet cooling temperatures defined in this specification.

**Center Frequency**

The center frequency shall be 805 MHz.

**Forward Power**

The maximum peak power that the load shall absorb is 600 kW with the worst case pulse format described in Section 1.0 above with the flow rate of =30 gpm of water.

**Bandwidth**

Except as otherwise noted the load shall meet all requirements of this specification over ± 12 MHz centered at the center frequency.

**VSWR**

For all conditions described in this specification the VSWR of the load shall be less than 1.07:1 over ± 1.0 MHz centered at the center frequency and less than 1.15:1 over ± 12 MHz centered at the center frequency.

### *2.2.12. SNS 402.5 MHz, 2.5 MW, and 805 MHz, 5 MW Transmitter Specification*

***Introduction***

This specification provides the requirements for a transmitter for the Spallation Neutron Source (SNS) accelerator project. The transmitter shall be compatible with one 2.5 MW pulsed klystron amplifier at 402.5 MHz or with one **5 MW** pulsed klystron amplifier at **805 MHz**. Klystron power refers to the klystron's peak RF output power. The klystrons shall be operated with up to an 8% duty factor with variable pulse repetition frequency (prf) which can be varied between ***1 and 120 Hz***. The transmitter shall meet all specified requirements at all pulse repetition frequencies between ***1 and 120 Hz.*** The klystrons are operated with a pulsed cathode voltage. The maximum pulsed voltage and current shall be 135 kV and 40 A, respectively. The maximum peak operating beam power (the product of cathode voltage and current) shall be = 5 MW and the maximum average power shall be = 500 kW.

The ***zero to peak value*** rise time of the cathode voltage and current pulse will vary between 50 to 150 microseconds. The flat top time of the cathode voltage and current ***will be between 0.01 and 1.333 milliseconds when the prf is = 60 Hz. When the prf is between 60 Hz and 120 Hz the flat top time of the cathode voltage and current will be between 0.01 milliseconds and 0.08/prf.*** The fall time of the cathode voltage pulse from 100% of the peak voltage to 20% of the peak voltage will vary between ***50 and 150 microseconds***. The fall time of the voltage from 20% of peak voltage to zero shall be ***150 to 250 microseconds***. All functions required by this specification shall be compatible with this pulse format and over these ranges of rise and fall times. This shall require that many of the measurement and interlock functions described in this specification to be based on sample and hold circuits.

Figure 1 illustrates all the major equipment groups that make up the RF system. This grouping is a functional grouping and is not necessarily representative of the physical configuration of the RF system. The shaded boxes in the figure represent items being purchased under this specification. Those boxes which are not shaded are being furnished separate from this specification by Los Alamos National Laboratory (LANL).

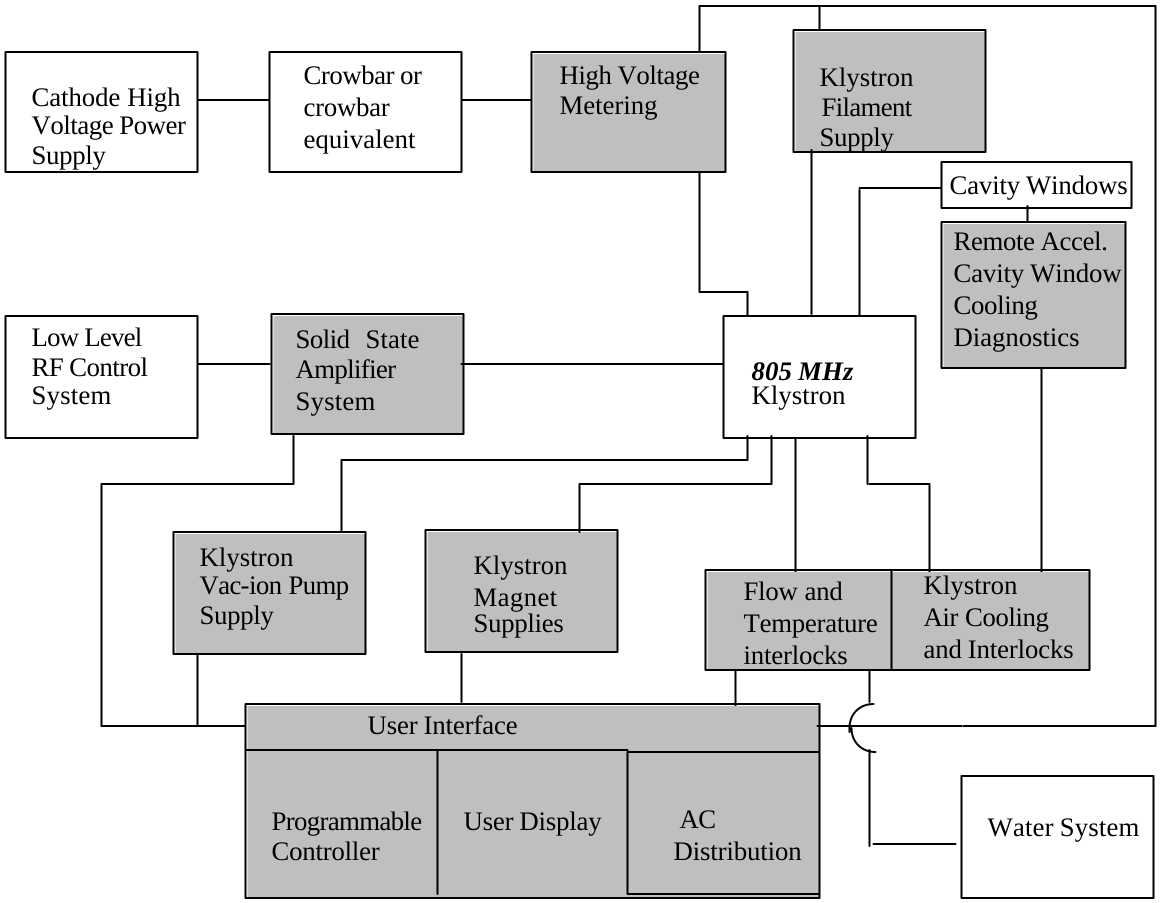


Figure 1. System Block Diagram

### *2.2.13. SNS 805 MHz, 550 kW Klystron Transmitter Specification*

***Introduction***

This specification provides the requirements for a 805 MHz, 550 kW klystron transmitter for the Spallation Neutron Source (SNS) accelerator project. The transmitter shall support six 550 kW pulsed klystron amplifiers at 805 MHz. Klystron power refers to each klystron's peak RF output power. The klystrons shall nominally be operated at a 9% duty factor at 60 Hz and may be operated with a variable pulse repetition frequency (prf) which can be varied between 1 and 120 Hz. The transmitter shall meet all specified requirements at all pulse repetition frequencies between 1 and 120 Hz. The transmitter shall meet all specified requirements independent of whether the cathode pulses are 60 Hz line synchronized or unsynchronized. The klystrons are operated with a pulsed cathode voltage. The maximum pulsed voltage and current shall be 80 kV and 13 A per klystron or 78 A per transmitter. The maximum peak operating beam power per klystron (the product of cathode voltage and current) shall be = 1 MW and the maximum average beam power per klystron shall be = 90 kW.

The zero to peak value rise time of the cathode voltage and current pulse will vary between 50 to 150 microseconds. The flat top time of the cathode voltage and current will be between 0.01 and 1.5 milliseconds when the prf is = 60 Hz. When the prf is between 60 Hz and 120 Hz the flat top time of the cathode voltage and current will be between 0.01 milliseconds and 0.09/prf. The fall time of the cathode voltage pulse from 100% of the peak voltage to 20% of the peak voltage will vary between 50 and 150 microseconds. The fall time of the voltage from 20% of peak voltage to zero shall be 150 to 250 microseconds. All functions required by this specification shall be compatible with this pulse format and over these ranges of rise and fall times. This shall require that many of the measurement and interlock functions described in this specification to be based on sample and hold circuits.

Figure 2 illustrates all the major equipment groups that make up the RF system. This grouping is a functional grouping and is not necessarily representative of the physical configuration of the RF system. The shaded boxes in the figure represent items being purchased under this specification. Those boxes which are not shaded are being furnished separate from this specification by Los Alamos National Laboratory (LANL).

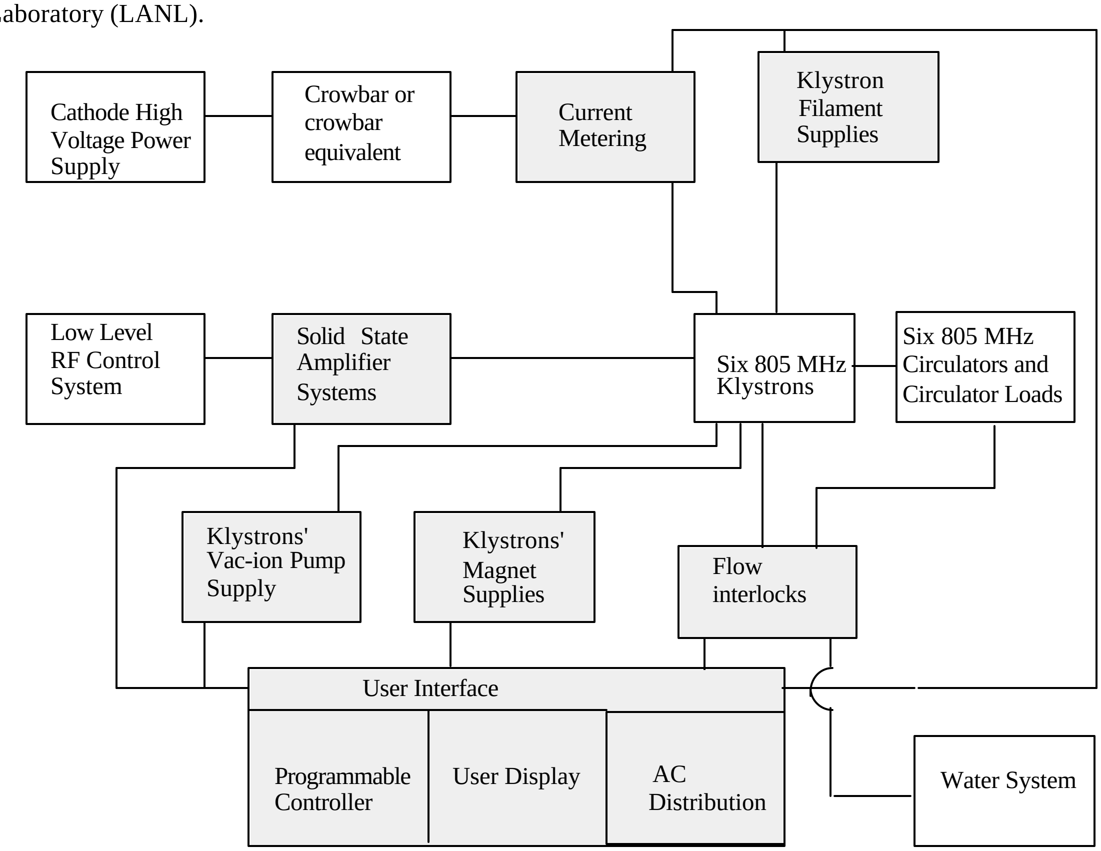



Figure 2. System Block Diagram

### 2.3 Waveguide layouts

#### 2.3.1 RFQ waveguide layout

LBNL has primary responsibility for the RFQ waveguide, including the circulator, splitters, and window/coupler assemblies.

#### 2.3.2 DTL waveguide layout

The DTL waveguide layout varies considerably with each module. Two representative layouts are given, one of which does not go through the angled waveguide chase between the klystron gallery and the accelerator (Figure 3), and one which does go through the angled waveguide chase (Figure 4).

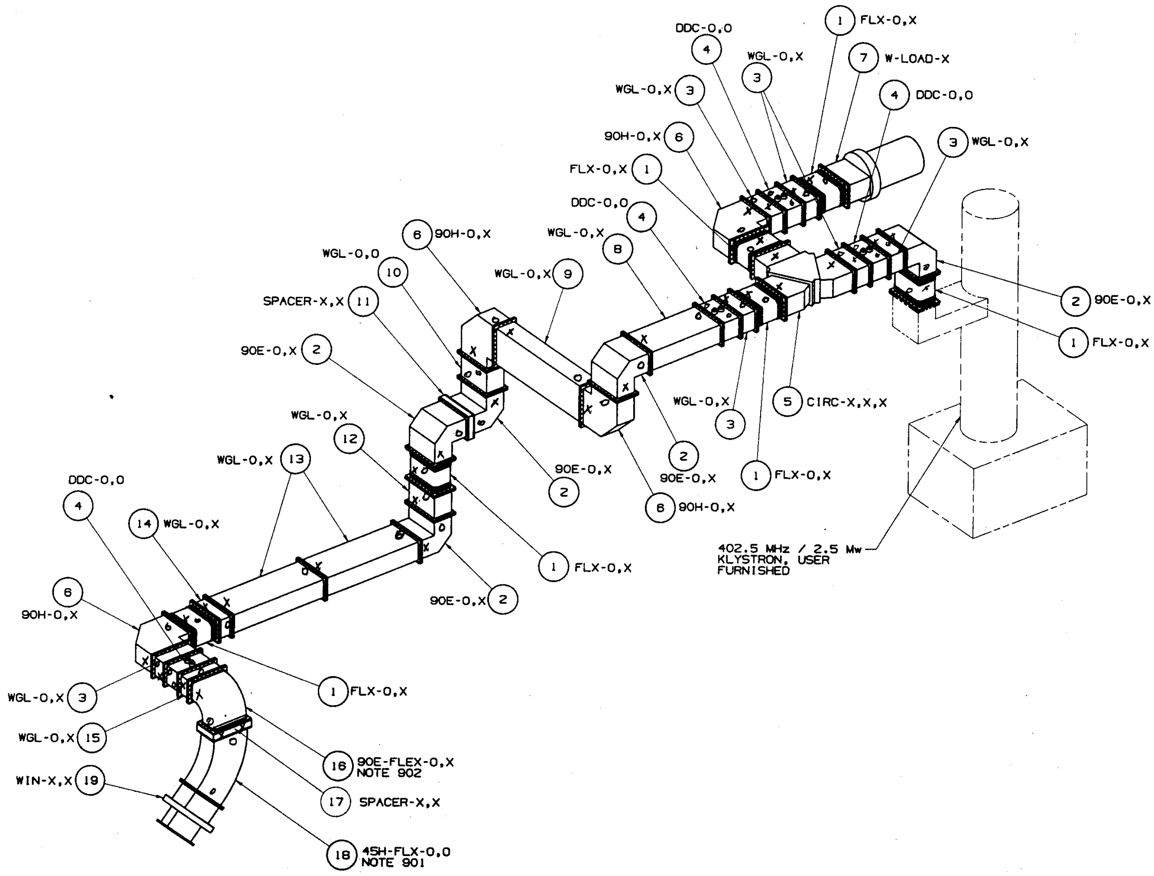



Figure 3. DTL layout which does not go through an angled waveguide chase

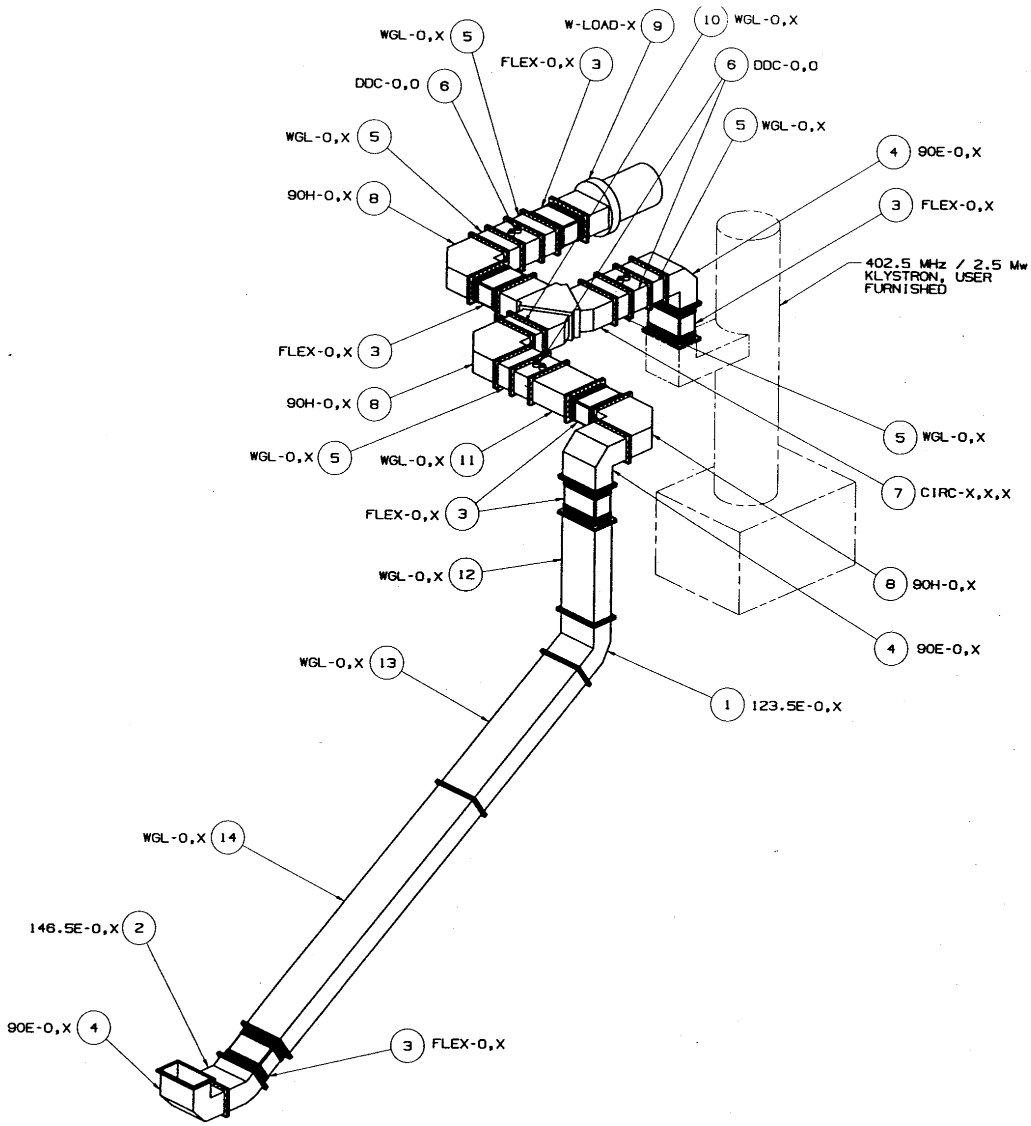



Figure 4. DTL waveguide which goes through an angled waveguide chase

### *2.3.3 CCL waveguide layout*

The CCL waveguide is the only waveguide system that includes a split. The output of each 5 MW is split into 2 drives to the CCL. Figure 5 shows a representative CCL waveguide run.

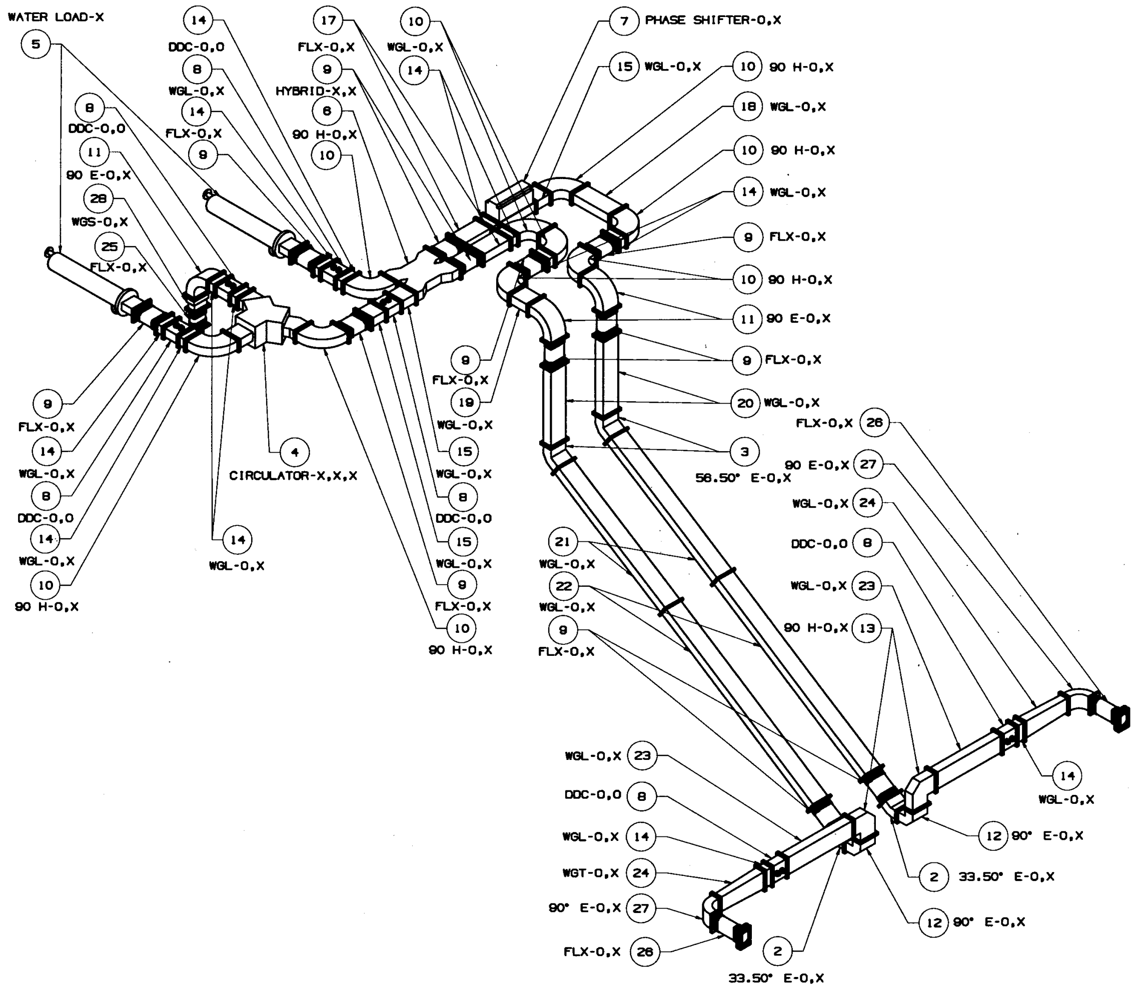



Figure 5. CCL waveguide run showing the split and the angled waveguide through the chase.

### *2.3.4 SRF waveguide layout*

The SRF waveguide layout varies from the room temperature waveguide runs in two ways. There are multiple klystrons per transmitter ( 5 or 6), and the window/coupler assembly is the responsibility of Jefferson Lab.

One transmitter's waveguide configuration is shown in Figure 6. The primary routing of the waveguide from the transmitter to the waveguide chases is shown. Not shown is the waveguide through the chases to the accelerator tunnel.

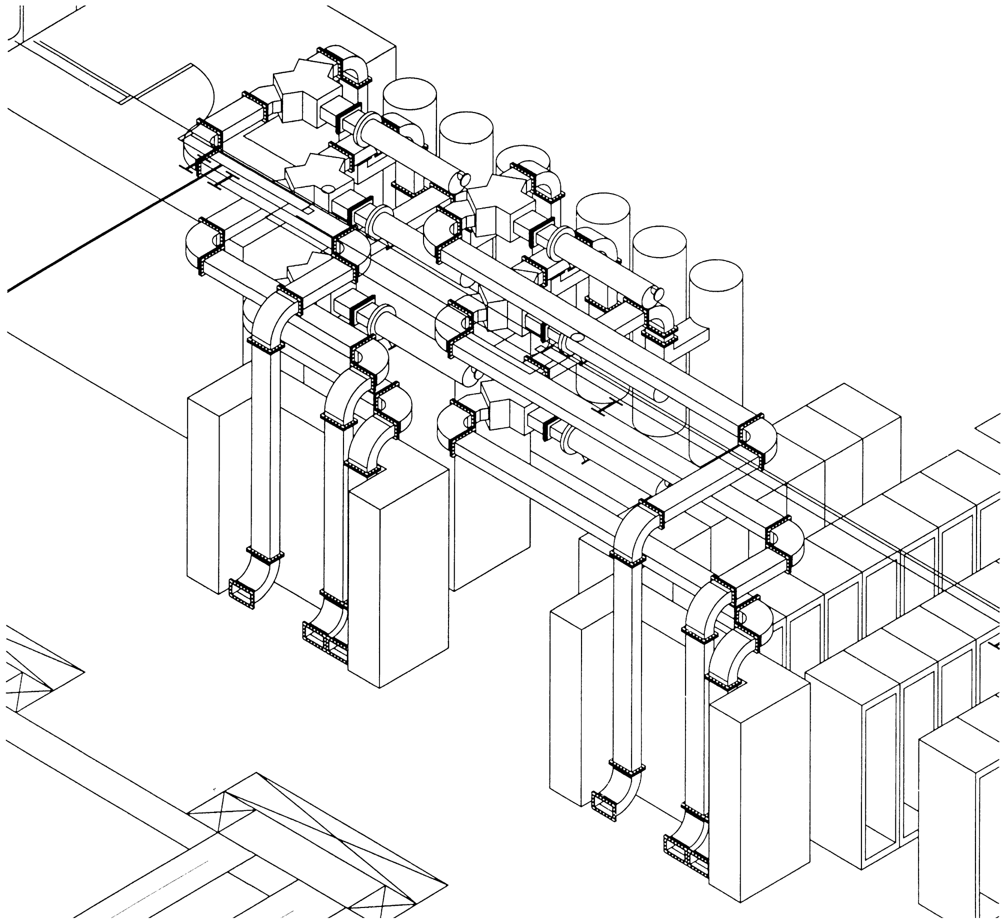


Figure 6. SRF waveguide layout for one transmitter, showing 6 klystrons

Figure 7 shows one of the SRF waveguide layouts from one transmitter. Each run is relatively simple. The complication comes, as seen in Figure 6, with the density of runs from each transmitter.

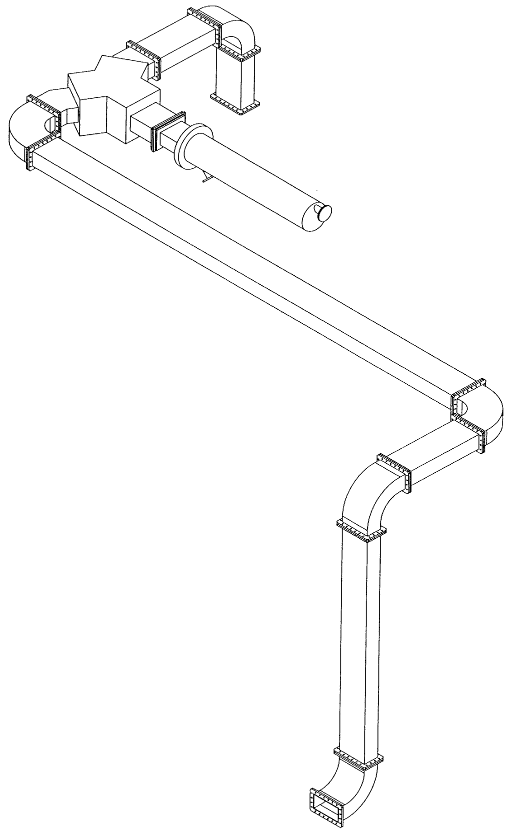


Figure 7. One SRF waveguide layout, not including the waveguide run through the chase to the accelerator

# 3. High Voltage Power Conditioning Design Parmeters

### *3.1. System Parameters. Normal Conducting Linac Klystron Power Requirements*

| | |
|---|---|
| Voltage, peak | 140 kV |
| Current, peak | 90 A |
| Average Power, maximum | 1 MW |
| Peak Power, maximum | 11 MW |
| Rep Rate, max | 120 Hz |
| Pulse width, max (including up to 0.1 ms risetime) | 1.25 ms |
| Number of 402.5 MHz klystrons per supply | 2, except first system = 3 |
| Number of 805 MHz klystrons per supply | 1, except HEBT system = 2 |

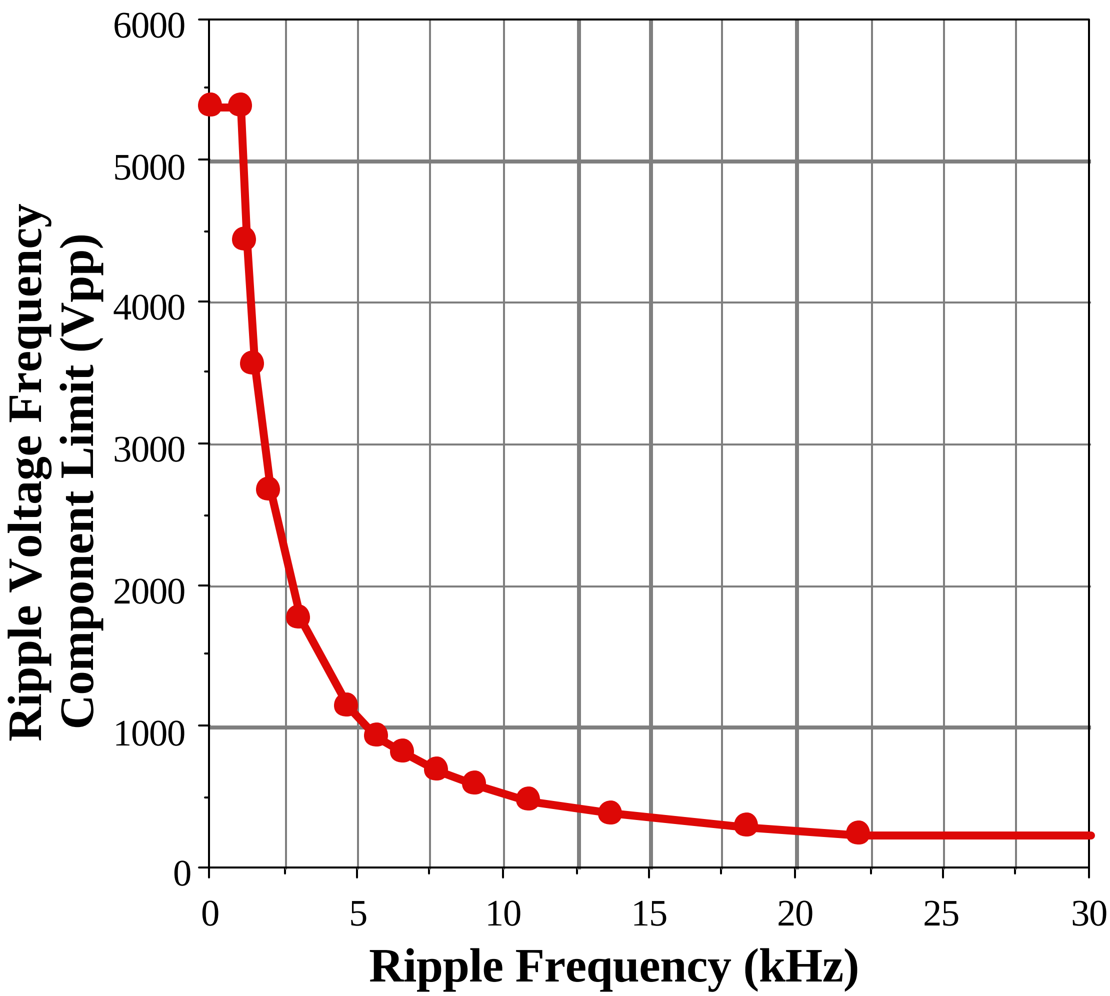
### *3.1.1 Detailed Parameters for 140 kV HV system for the normal conducting linac*

| | |
|---|---|
| Rise Time to stable flat top | = 0.1 ms |
| Output stability for settings from 25 to 100% of full scale | ±0.5% |
| Current range, peak | 5 to 90 A |
| Input voltage | 13.8 kV AC RMS ±3%, 3 phase, 60 Hz |

Efficiency for voltages between 85% and 100% of the maximum rated voltage and 75% and 100% of the maximum rated current = 85%

The major sub unit of the HVPPS located within the klystron gallery shall deposit no more than 30 kW of heat into the air of the klystron gallery under all operating conditions.

Absolute maximum values for the frequency components of the output voltage ripple during the stable flat top portion of the output pulse for frequencies between 750 Hz and 30 kHz:




***3.2. System Parameters. Superconducting Linac Klystron Power Requirements***

| | |
|---|---|
| Voltage, peak | 80 kV |
| Current, peak | 140 A |
| Average Power, maximum | 1 MW |
| Peak Power, maximum | 11 MW |
| Rep Rate, max | 120 Hz |
| Pulse width, max (including up to 0.1 ms risetime) | 1.4 ms |
| Number of klystrons per supply | 11 or 12 |

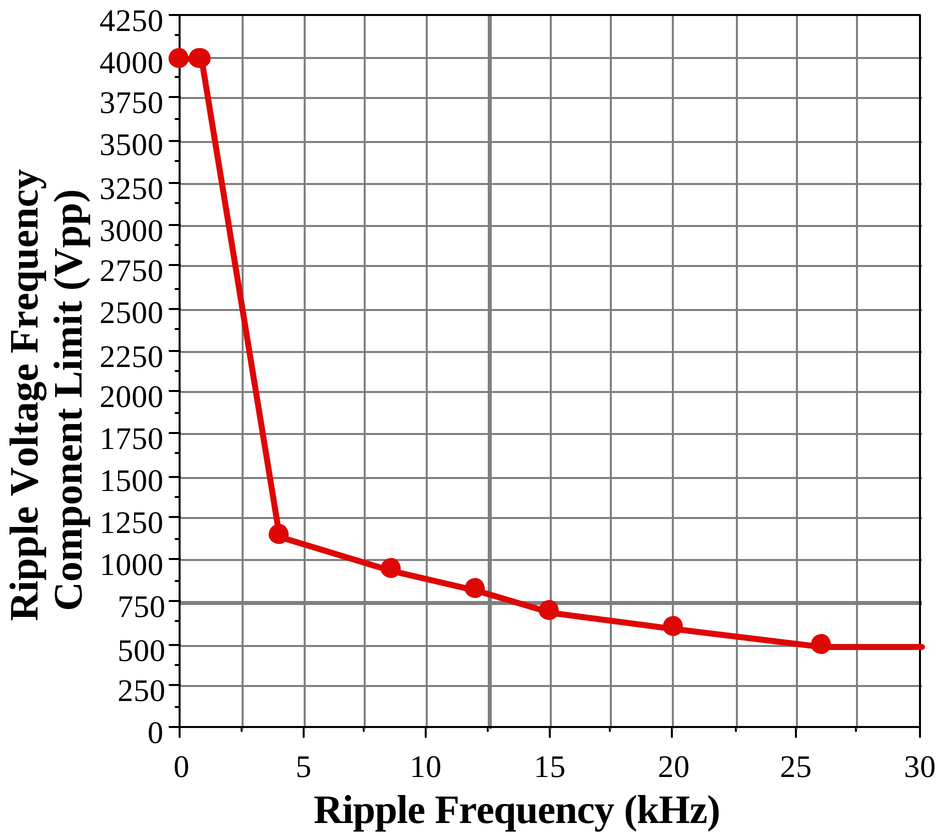
***3.2.1 Detailed Parameters for 80 kV HV system for the superconducting linac***

| | |
|---|---|
| Rise Time to stable flat top | = 0.1 ms |
| Output stability for settings from 50 to 100% of full scale | ±0.5% |
| Current range, peak | 2 to 140 A |
| Input voltage | 13.8 kVAC ±3%, 3 phase, 60 Hz |

Efficiency for voltages between 85% and 100% of the maximum rated voltage and 75% and 100% of the maximum rated current = 85%

The major sub unit of the HVPPS located within the klystron gallery shall deposit no more than 30 kW of heat into the air of the klystron gallery under all operating conditions.

Absolute maximum values for the frequency components of the output voltage ripple during the stable flat top portion of the output pulse for frequencies between 750 Hz and 30 kHz:



# 4. RF Controls Design Parameters

### 4.1. System Level Parameters

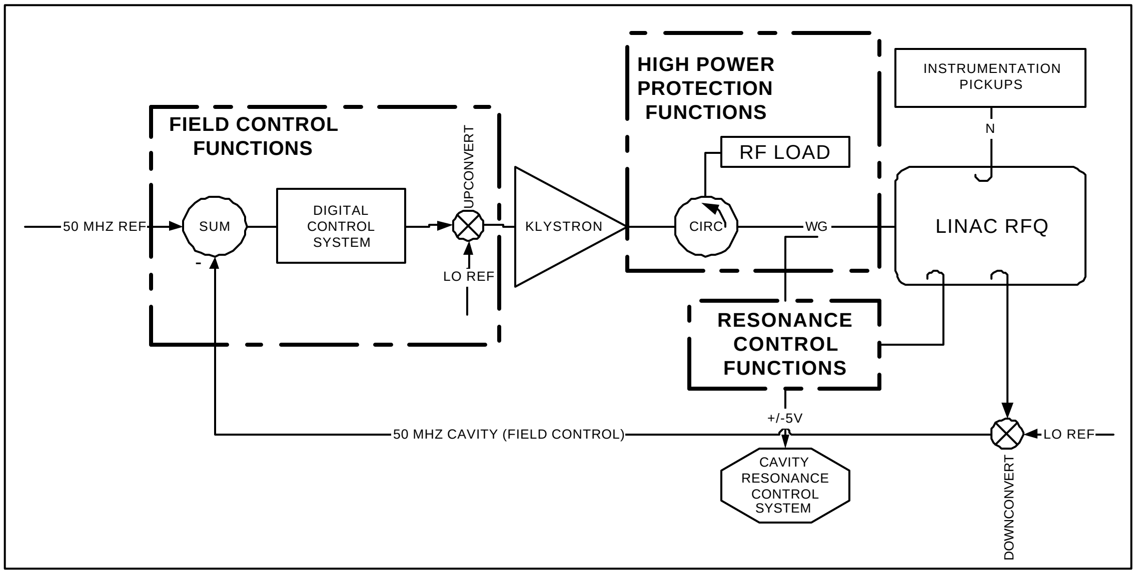
| Parameter | Value |
|---|---|
| Pulse Rep Rate | 60.0 Hz (and, possibly, 10.00 Hz interleaved) |
| MacroPulse Width | 0.945 ns (645 ns ON/300 ns OFF), 1.1886 MHz |
| LINAC Length | Approximately 335 m |
| RFQ<br>Resonance Control Requirement | $F_0$: 402.5 MHz ± 15 kHz<br>$Q_L$ = 3,300<br>BW = 122 kHz |
| DTL<br>Resonance Control Requirement | $F_0$: 402.5 MHz ± 2 kHz<br>$Q_L$: 25,000 (smallest bandwidth case)<br>BW = 16 kHz |
| CCL<br>Resonance Control Requirement | $F_0$: 805 MHz ±10 kHz<br>$Q_L$: 10,000 (smallest bandwidth case)<br>BW = 80 kHz |
| SRF ß=0.61<br>Resonance Control Requirement | $F_0$: 805 MHz ±500 Hz<br>$Q_L$: 733,000 ±20%<br>BW = 1 kHz |
| SRF ß=0.61<br>Lorentz constant | 2.9 Hz/(MV/m)^2 |
| SRF ß=0.81<br>Resonance Control Requirement | $F_0$: 805 MHz ±500 Hz<br>$Q_L$: 699,000 ±20%<br>BW = 1 kHz |
| SRF ß=0.81<br>Lorentz constant | 1.2 Hz/(MV/m)^2 |
| Field Control Requirement, all cavities | Amplitude Tolerance: ± 0.5% Max in steady state, ± 0.75% during beam turn-on transient.<br>Phase Tolerance: ± 0.5° Max in steady state, ±0.75° during beam turn-on transient. |

### 4.2 Detailed design parameters

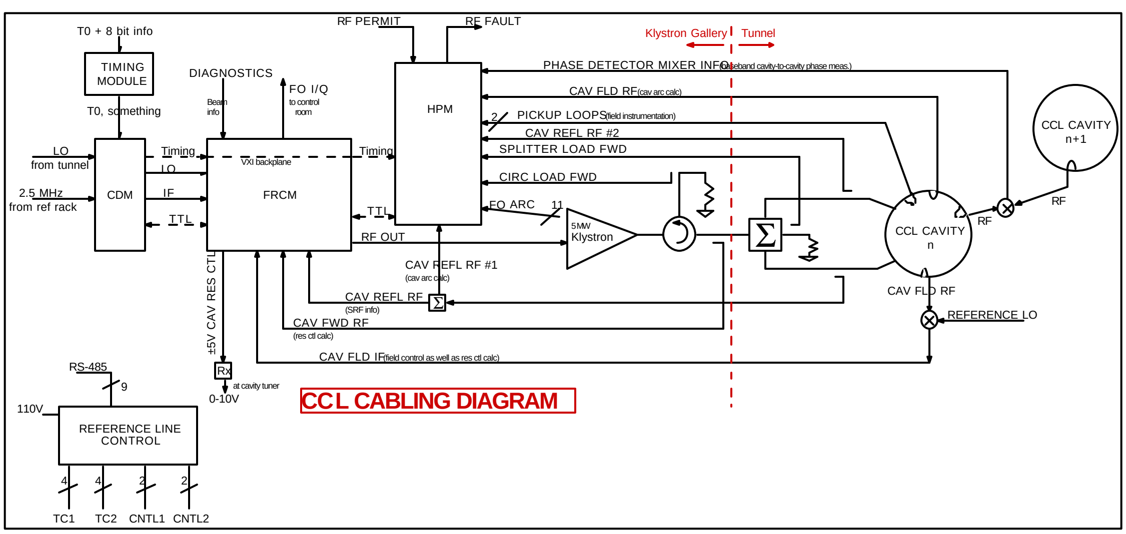
RF Control System (RFCS) Functions

The four primary functions of the RFCS are control of the cavity fields (Field Control), detection and control of the cavity resonance (Resonance Control), protection of the klystrons and cavities from high power faults (High Power Protection) and the radio frequency reference distribution subsystem. See Figure below.

## System Functional Block Diagram




The selected architecture for the RF Control System is VXIbus. Each of these global functions, with the exception of the Reference Generation and Distribution, will be located on a VXIbus module. In broad terms, the Field, Resonance, and Amplifier Control functions are performed by a Field / Resonance Control Module (FRCM) in conjunction with a Clock Distribution Module (CDM); and the High Power Protect function is performed by a HPRF Protect Module (HPM). The figure below shows one example (CCL) of how these functions are interconnected in the various stages of the LINAC.




A description of the modules is given below:

Field / Resonance Control Module (FRCM)

The FRCM continuously monitors both the cavity field amplitude and phase and the actual cavity resonance frequency. The field control portion of the module minimizes deviations of the cavity field amplitude and phase from their respective setpoints. The resonance control portion of the module, depending on the magnitude of the error between the actual resonance frequency and the desired operating frequency, takes actions to move the cavity resonance to the operating frequency, either by slewing the drive frequency, issuing a correction signal to the Resonant Cavity Control System (RCCS), or both.

High Power Protection Module (HPM)

The High Power Protection Module (HPM) continuously monitors the high power RF distribution system using RF power detectors, fiber optic arc detectors, and the vacuum permit system. It can shut off the RF carrier and/or the injector in the event of faults.

Clock Distribution Module (CDM)

The Clock Distribution Module (CDM) generates the master timing signals for the other LANL modules in the VXIbus crate. It also receives timing information from the Brookhaven National Laboratory's (BNL) Event Link Module and reformats it for the LBUS (Local Bus) on the crate backplane for use by the various modules.

Frequency Reference System (REF)

The key to operating the accelerator RF control system is a stable frequency reference distributed to the various control racks. The reference system is designed to maintain a total phase error in the reference frequencies of $\pm 0.1^{o}$ over the entire length of the accelerator. To minimize the error contribution of the frequency reference system, the reference signals are distributed in insulated, temperature-controlled coaxial lines.

Reference Line specifications

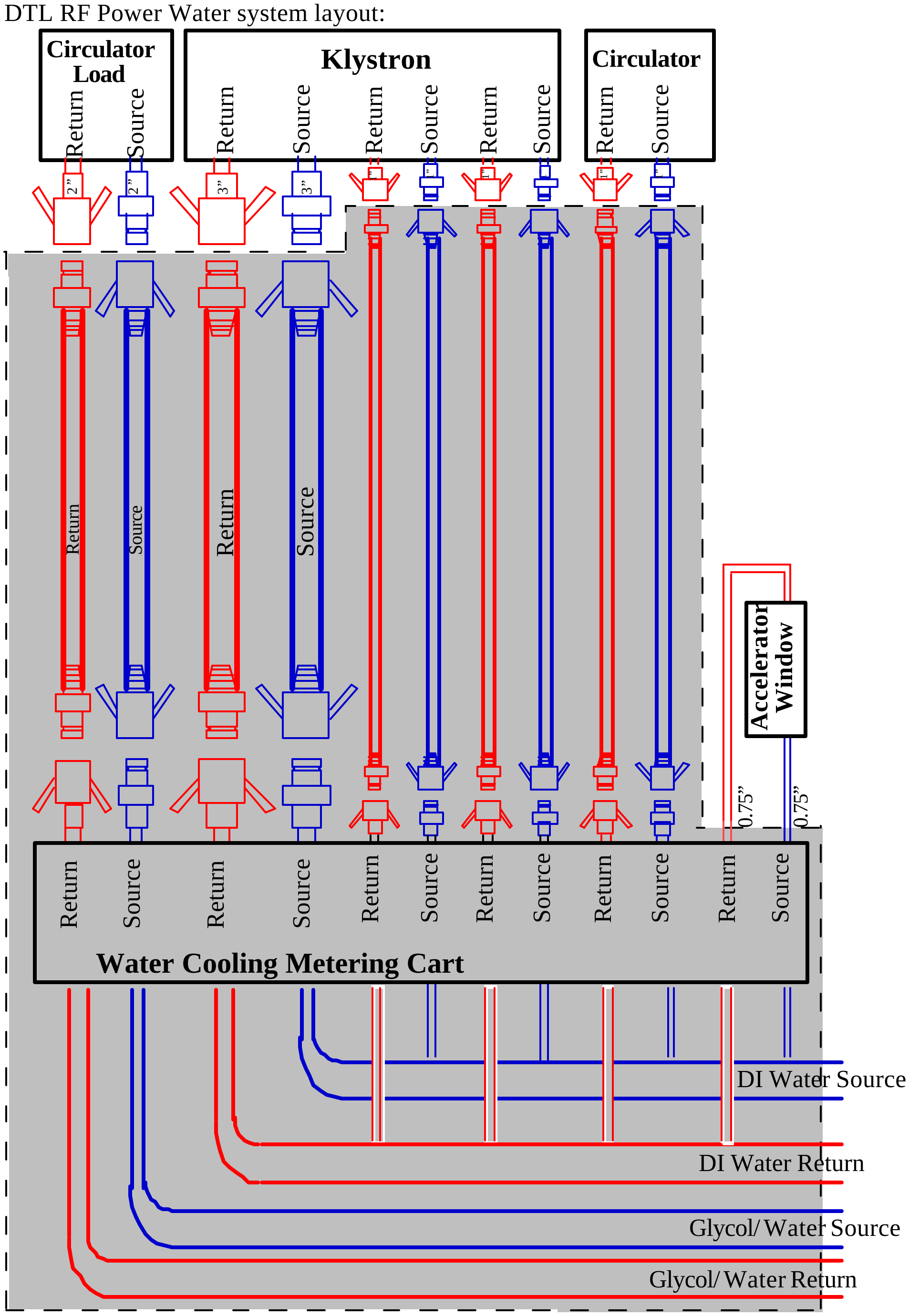
| **Parameter** | **Specification** |
|---|---|
| Frequency: | 755 MHz or 352.5 MHz (depending on location) |
| Length: | 335 m |
| Phase Stability: | ±0.1° @ 755 MHz |
| **Taps** | |
| Number of Taps: | 95 |
| Tap Power: | +21 dBm |
| Tap Coupling: | > 20 dB, variable in 1 dB steps |
| Amplifier Power: | 50 Watts (+47 dBm) |
| **Main Line** | |
| Line Type: | 3 1/8" rigid copper co-ax; pressurized with dry air |
| Line Lengths: | 20 ft. sections with slip joints every 100 ft. |
| Temperature Control Method: | Electric heater and controller every 100 ft. |
| Temperature Control Stability: | ±0.1° C (40° C nominal temperature) |
| Pressure Control: | +/- 1 torr |
| **IF Distribution Line** | |
| Line Type: | 3/8" Heliax for LO distribution to Clock Module |
| Line Lengths: | 100 ft. insulated and temperature controlled to ±0.1° C @ 40° C |

## 5. Interface Control

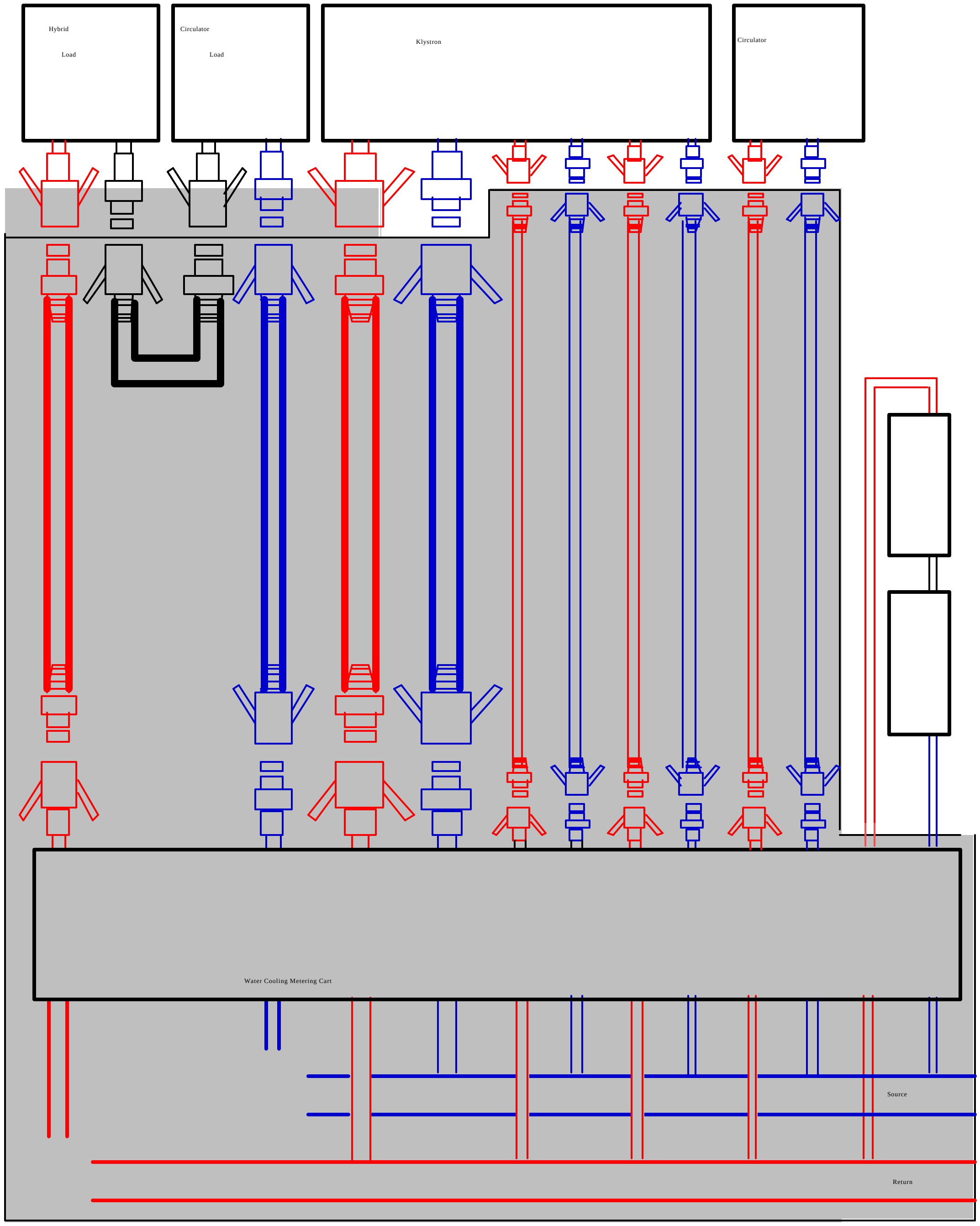
The majority of the interfaces for the RF system are through the RF control system. Some brief interfaces are shown below for the High Power RF and HV systems. The majority of their interfaces are contained in the detailed specifications of the hardware.

### *5.1. High Power RF Interfaces*

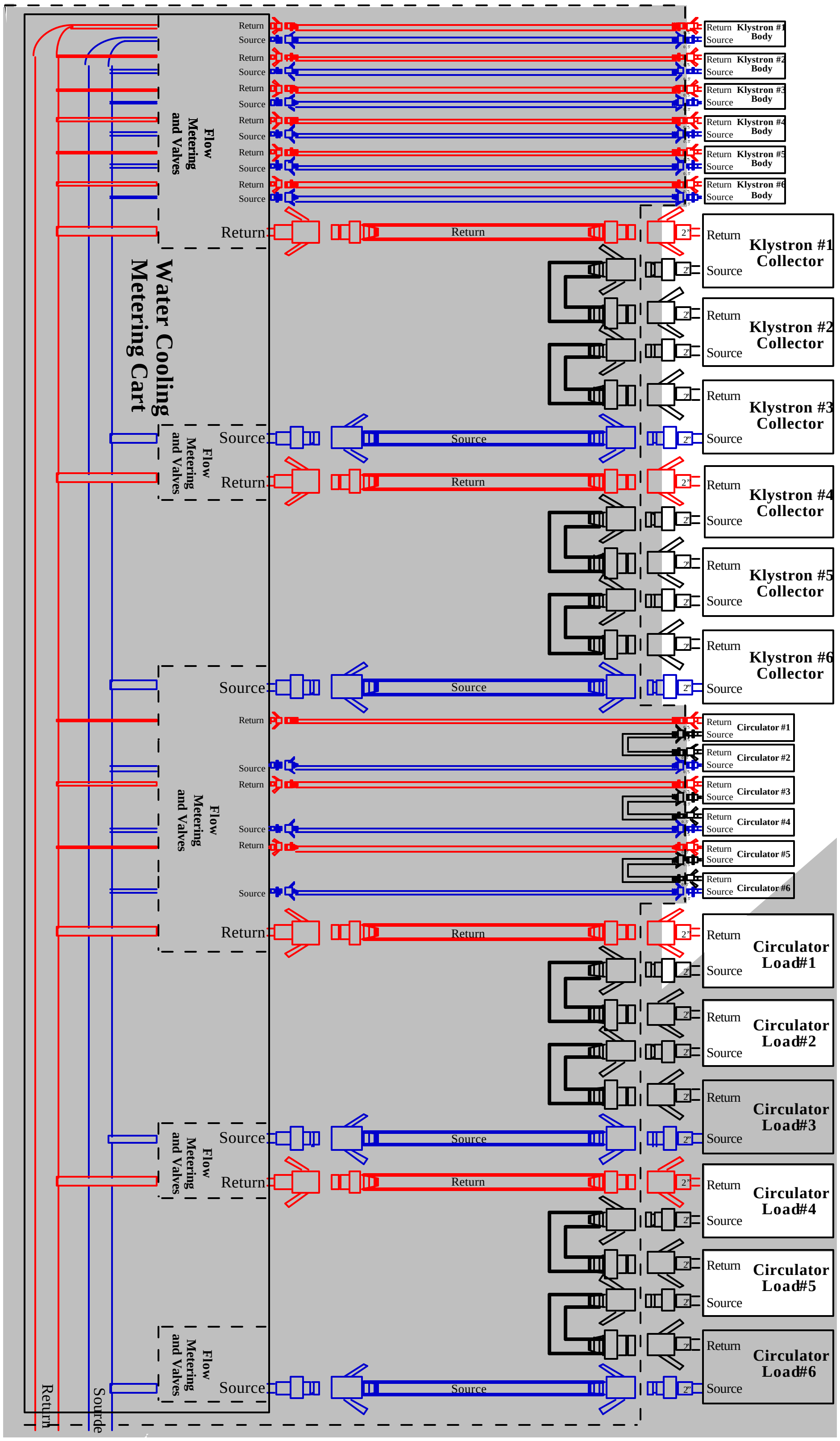
DTL RF Power Water system layout:



CCL RF Power Water System Layout:




SRF RF Power Water System Layout:



Water Cooling Metering Cart
Flow Metering and Valves
Return
Source
Klystron #1 Body
Klystron #2 Body
Klystron #3 Body
Klystron #4 Body
Klystron #5 Body
Klystron #6 Body
Klystron #1 Collector
Klystron #2 Collector
Klystron #3 Collector
Klystron #4 Collector
Klystron #5 Collector
Klystron #6 Collector
Circulator #1
Circulator #2
Circulator #3
Circulator #4
Circulator #5
Circulator #6
Circulator Load#1
Circulator Load#2
Circulator Load#3
Circulator Load#4
Circulator Load#5
Circulator Load#6

### *5.2. HV Power Conditioning Interfaces, 80 kV and 140 kV systems*

***AC Power Source for HVPPS***

Input Voltage

The input voltage shall be 13.8 kV AC RMS ±3%, 3 phase, 60 Hz.

Unbalance

Under normal conditions, the voltage unbalance from phase to phase in the power provided by ORNL shall be = 3.8%.

Harmonic Distortion

The input current harmonics generated at the 13.8 kV input by an individual HVPPS system and by the set of all HVPPS systems under all operational scenarios defined in this specification shall conform to the recommended practices defined in IEEE Std 519-1992.

Power Factor

The displacement component of the power factor that HVPPS presents to the source shall be = 0.93 when operating at voltages between 85% and 100% of the maximum rated voltage and 75% and 100% of the maximum rated current.

***Physical Layout***

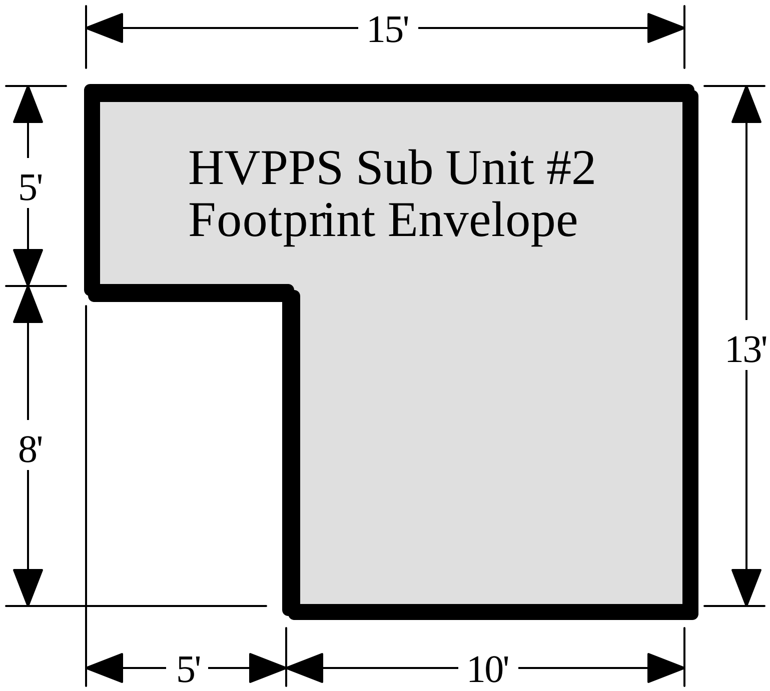
The HVPPS shall fit within the areas described below. The HVPPS system shall be divided into three separate major sub units and a small remote sub unit. The floor loading of each sub unit shall be = 500 pounds per square foot. The location and maximum area allowed for each sub unit is as follows.

Sub Unit #1

A local control rack will be located within the klystron gallery. The local control rack shall be a standard 19 inch rack that is = 8 feet high. The maximum distance from the control rack to sub unit #2 shall be = 100 feet.

Sub Unit #2

This sub unit shall occupy no more than an "L" shaped floor space that is 13 feet by 15 feet in the longest dimensions as shown in figure below. All parts of sub unit #2 shall fit within the "L" shaped footprint envelope shown in figure. The "L" shaped footprint envelope shall have a perimeter whose sides are 15 feet, 13 feet, 10 feet, 8 feet, 5 feet and 5 feet; as shown in figure 3. The height of this sub unit shall be = 10 feet.




The HVPPS sub unit #2 footprint envelope.

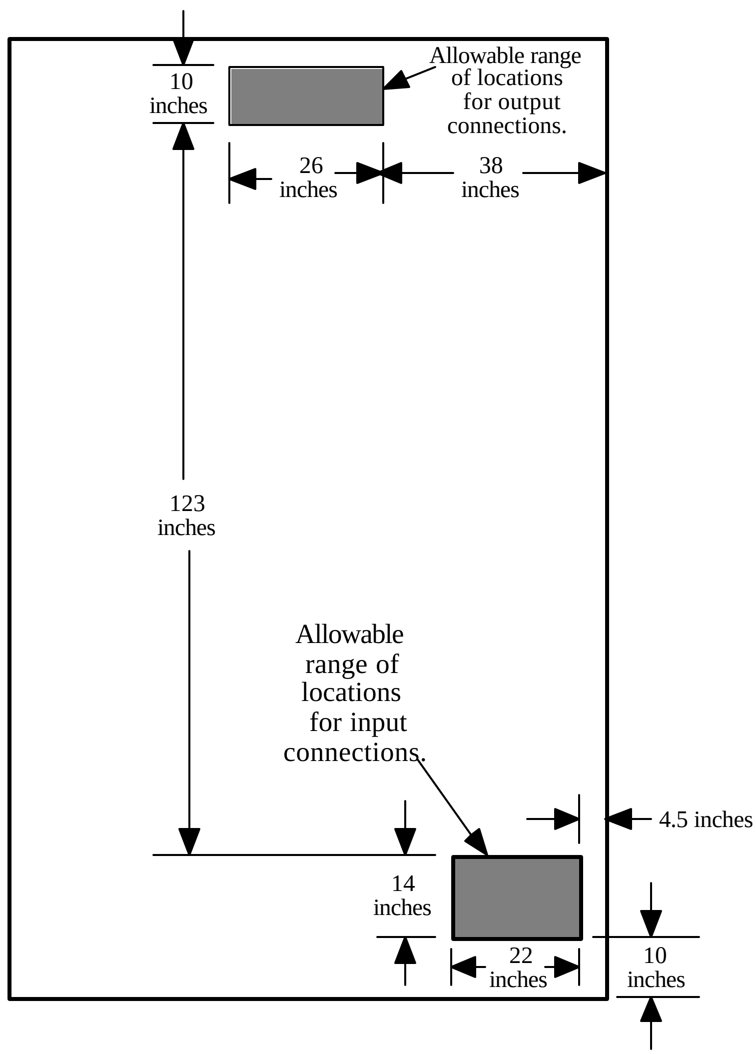
This sub unit shall be capable of being disassembled into moveable components without the use of an overhead crane. All components of this sub unit shall be capable of being transported by fork lift down a aisle with a width of 7 feet and a height of 15 feet.

Sub Unit #3

The exterior sub unit shall comply with the 1993 National Electrical Code and shall be NEMA 3R or greater. The maximum size of this sub unit shall be 8.5 feet by 13.5 feet. The floor loading of this sub unit on the slab shall be = 500 pounds per square foot. Insulating oil will not be used in the exterior sub unit.

ORNL will provide a weatherized switchgear cabinet adjacent to one of the short sides of the sub unit. The placement of the ORNL switchgear will prevent any access to this side of the sub unit. Access to this side of the sub unit shall not be required for servicing or maintenance after the sub unit is installed. A 6 inch diameter conduit provided by ORNL shall connect the sub unit to the switchgear. The sub unit shall be compatible with an input connection of this type. In addition, the sub unit shall also be compatible with an input connection to a 6 inch diameter underground conduit entering the underside of the unit. The sub unit shall be compatible with all input conduit connections from below that fall within the shaded area for input connections as shown in figure below. These locations are shown as viewed from ABOVE the sub unit.

A 6 inch diameter underground conduit with a minimum bend radius of 2 feet shall be provided by ORNL and shall be available to connect any high voltage connections between the exterior HVPPS sub unit and interior sub unit #2. In addition, a 2 inch diameter underground conduit shall be provided by ORNL to provide cooling and control power and connect control and fiber optic lines between the exterior HVPPS sub unit and any and all interior sub units. Both conduits will stub up through the concrete pad. These conduits shall stub up BELOW THE EXTERIOR SUB UNIT near the end opposite from the switchgear.




The sub unit shall be compatible with 6" conduit connections that fall within the shaded areas.

All cable and busway termination compartments and terminations shall comply with the 1999 National Electrical Code and shall be NEMA 3R or greater for all equipment located outside the facility. The length of these conduits is different for each HVPPS system but shall be between 75 feet and 300 feet.

Remote Sub Unit

A remote sub unit indicates the "real time" output voltage and current. ORNL shall mount the remote sub unit to a standard "DIN rail" located near the back of a standard 19 inch rack. The maximum dimensions of the remote sub unit shall be such that the remote sub unit can fit within a cube that is 6 inches on each side. The remote sub unit shall not be visible from the front of the rack under normal operation.

### *5.3. RF Controls Interfaces*

#### *5.3.1. RFCS RFQ Interface*

RFQ External Inputs/Outputs

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| CDM | $T_0$ In | $T_0$ signal from Timing Module to CDM - **TBD** |
| CDM | 352.5 LO In | LO Signal from Reference system in tunnel. 352.5 MHz/+10 dBm |
| CDM | 2.5 MHz In | 2.5 MHz / +10 dBm from Reference Rack |
| FRCM | Diagnostic In | Beam feed forward input from Diagnostic Group Rack – **TBD** |
| FRCM | FO I/Q Out | Pair of Digital FO data links to Control Room patch panel – **TBD** |
| FRCM | RCCS Out | ±5V error signal to RFCS RCCS Differential amp box located at RCCS rack. Output of Differential amp is 0-10V to RCCS. |
| FRCM | CAV Field IF In | 50 MHz/+0 dBm cavity field reference |
| FRCM | CAV FWD RF In | Forward power into splitter – 402.5 MHz/+10 dBm max |
| FRCM | CAV RFL RF In | Reflected power from splitter – 402.5 MHz/+10 dBm max |
| FRCM | RF Out | 402.5 MHz feed to transmitter |
| HPM | RF_PERMIT In | Input from MPS or Vacuum System – Opto-isolated Rx at HPM. HIGH = OK |
| HPM | RF_FAULT* Out | Output to MPS – Opto-isolated Rx at MPS. HIGH = OK |
| HPM | RF 0 In | Cavity Field Probe – 402.5 Mhz/+10 dBm Max |
| HPM | RF 1 In | Klystron-Circulator Forward Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 2 In | Klystron-Circulator Reflected Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 3 In | Circulator-Splitter Forward Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 4 In | Circulator-Splitter Reflected Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 5 In | 16:1 Multiplexer output – 402.5 Mhz/+10 dBm Max<br>8 cavity field probes – Channel assignments **TBD**<br>8 window forward power - Channel assignments **TBD** |
| HPM | RF 6 In | 16:1 Multiplexer output – 402.5 Mhz/+10 dBm Max<br>8 cavity field probes - Channel assignments **TBD**<br>8 window reflected power - Channel assignments **TBD** |
| HPM | BB 7 In | Not used |
| HPM | FOARC 00 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| HPM | FOARC 01 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 02 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 03 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 04 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 05 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 06 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 07 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 08 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 09 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 10 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 11 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 12 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 13 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| REF | TC 1 In | Input from Thermocouple 1 in the reference line in the tunnel. |
| REF | TC 2 In | Input from Thermocouple 2 in the reference line in the tunnel. |
| REF | CNTL 1 Out | 115VAC out to heater strip 1 in the reference line in the tunnel. |
| REF | CNTL 2 Out | 115VAC out to heater strip 2 in the reference line in the tunnel. |
| REF | RS-485 COM | Bi-directional RS-485 communications between REF heater controller and EPICS. |

RFQ Cable Lists

| Signal Description – RFCS RFQ Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Cavity field to mixer RF port | RF | Heliax | Tunnel | |
| Tunnel reference line to mixer LO port | RF-50MHz | Heliax | Tunnel | |
| Cavity field IF from mixer to RFCS (FRCM) | 50 MHz | Heliax | Tunnel to gallery | |
| Cavity field pickup loops for instrumentation (>4 requires a mux) n=16 (will be mux'd to two) | RF | Heliax | Tunnel to gallery | yes |
| Pickup loop for cavity arc detection (HPPS) Cavity to RFCS | RF | Heliax | Tunnel to gallery | |
| D/C on W/G feed back to RFCS (HPPS) (for cavity arc detection) | RF | Heliax | Tunnel to gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | gallery | |
| D/C at 1 of 8 feeds to cavity (n=8) will go to 16:1 mux for monitoring fwd/refl at cavity | RF | Heliax | Tunnel to gallery | yes |
| D/C at 1 of 8 feeds to cavity (HPPS). n=8. will go to 16:1 mux for monitoring fwd/refl at cavity | RF | Heliax | Tunnel to gallery | |
| Upstream of 8-way split. Back to HPPS | RF | Heliax | Gallery only ? | |
| Upstream of 8-way split. Back to HPPS | RF | Heliax | Gallery only ? | |
| Output to "Beam Off" Fast Protect system | TTL | TBD | Gallery | |
| Input from Machine Protect System– "OK for RF on" | TTL | TBD | Gallery | |
| Fiber optic arc detector signal from HPRF rack (where arc detectors are located). | TTL | TBD | Gallery | yes |

| Signal Description – RFCS RFQ Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Contains info about arc in waveguide. n=14 | | | | |

### 5.3.2. RFCS DTL and HEBT

DTL and HEBT External Inputs/Outputs

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| CDM | $T_0$ In | $T_0$ signal from Timing Module to CDM - **TBD** |
| CDM | 352.5 LO In | LO Signal from Reference system in tunnel. 352.5 MHz/+10 dBm |
| CDM | 2.5 MHz In | 2.5 MHz / +10 dBm from Reference Rack |
| FRCM | Diagnostic In | Beam feed forward input from Diagnostic Group Rack – **TBD** |
| FRCM | FO I/Q Out | Pair of Digital FO data links to Control Room patch panel – **TBD** |
| FRCM | RCCS Out | ±5V error signal to RFCS RCCS Differential amp box located at RCCS rack. Output of Differential amp is 0-10V to RCCS. |
| FRCM | CAV Field IF In | 50 MHz/+0 dBm cavity field reference |
| FRCM | CAV FWD RF In | Forward power into splitter – 402.5 MHz/+10 dBm max |
| FRCM | CAV RFL RF In | Reflected power from splitter – 402.5 MHz/+10 dBm max |
| FRCM | RF Out | 402.5 MHz feed to transmitter |
| HPM | RF_PERMIT In | Input from MPS or Vacuum System – Opto-isolated Rx at HPM. HIGH = OK |
| HPM | RF_FAULT* Out | Output to MPS – Opto-isolated Rx at MPS. HIGH = OK |
| HPM | RF 0 In | Cavity Field Probe – 402.5 Mhz/+10 dBm Max |
| HPM | RF 1 In | Circulator Load Forward Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 2 In | Circulator – Cavity Reflected Power – 402.5 Mhz/+10 dBm Max |
| HPM | RF 3 In | Instrumentation Channel 1 – 402.5 Mhz/+10 dBm Max |
| HPM | RF 4 In | Spare |
| HPM | RF 5 In | Spare |
| HPM | RF 6 In | Spare |
| HPM | BB 7 In | Phase detector Input - ± 100 mV baseband |
| HPM | FOARC 00 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 01 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 02 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 03 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 04 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 05 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 06 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 07 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| REF | TC 1 In | Input from Thermocouple 1 in the reference line in the tunnel. |
| REF | TC 2 In | Input from Thermocouple 2 in the reference line in the tunnel. |
| REF | CNTL 1 Out | 115VAC out to heater strip 1 in the reference line in the tunnel. |
| REF | CNTL 2 Out | 115VAC out to heater strip 2 in the reference line in the tunnel. |

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| REF | RS-485 COM | Bi-directional RS-485 communications between REF heater controller and EPICS. |

RFCS DTL Cables

| Signal Description – RFCS DTL Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Cavity field to mixer RF port | RF | Heliax | Tunnel | |
| Tunnel reference line to mixer LO port | RF-50MHz | Heliax | Tunnel | |
| Cavity field IF from mixer to RFCS (FRCM) | 50 MHz | Heliax | Tunnel to Gallery | |
| Cavity field pickup loops for instrumentation | RF | Heliax | Tunnel to Gallery | No. only 1 |
| Pickup loop for cavity arc detection (HPPS)<br>Cavity to RFCS | RF | heliax | Tunnel to Gallery | |
| D/C on W/G feed back to RFCS (HPPS) (for cavity arc detection) | RF | Heliax | Tunnel to Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| Pickup-loop from upstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Pickup-loop from downstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Signal from mixer used as a phase detector. Mixer to HPPS | Quasi-DC | Coax (Times LMR 100?) | | |
| Output to “Beam Off” Fast Protect system | TTL | TBD | Gallery | |
| Input from cavity vacuum – “OK for RF on” | TTL | TBD | Gallery | |
| Fiber optic arc detector signal from HPRF rack (where arc detectors are located). Contains info about arc in waveguide. n=8 | TTL | TBD | Gallery | yes |

RFCS HEBT Cables

| Signal Description – RFCS HEBT Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Cavity field to mixer RF port | RF | Heliax | Tunnel | |
| Tunnel reference line to mixer LO port | RF-50MHz | Heliax | Tunnel | |
| Cavity field IF from mixer to RFCS (FRCM) | 50 MHz | Heliax | Tunnel to Gallery | |
| Cavity field pickup loops for instrumentation | RF | Heliax | Tunnel to Gallery | Yes 2 |
| Pickup loop for cavity arc detection | RF | Heliax | Tunnel to Gallery | |

| Signal Description – RFCS HEBT Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| (HPPS)<br>Cavity to RFCS | | | | |
| D/C on W/G feed back to RFCS (HPPS) (for cavity arc detection) | RF | Heliax | Tunnel to Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| Pickup-loop from upstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Pickup-loop from downstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Signal from mixer used as a phase detector. Mixer to HPPS | Quasi-DC | Coax (Times LMR 100?) | | |
| Output to "Beam Off" Fast Protect system | TTL | TBD | Gallery | |
| Input from Machine Protect System – "OK for RF on" | TTL | TBD | Gallery | |
| Fiber optic arc detector signal from HPRF rack (where arc detectors are located). Contains info about arc in waveguide. n=8 | TTL | TBD | Gallery | yes |

### *5.3.3. RFCS CCL*

CCL External Inputs/Outputs

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| CDM | $T_0$ In | $T_0$ signal from Timing Module to CDM - **TBD** |
| CDM | 755 LO In | LO Signal from Reference system in tunnel -- 755.0 MHz/+10 dBm |
| CDM | 2.5 MHz In | 2.5 MHz / +10 dBm from Reference Rack |
| FRCM | Diagnostic In | Beam feed forward input from Diagnostic Group Rack – **TBD** |
| FRCM | FO I/Q Out | Pair of Digital FO data links to Control Room patch panel – **TBD** |
| FRCM | RCCS Out | ±5V error signal to RFCS RCCS Differential amp box located at RCCS rack. Output of Differential amp is 0-10V to RCCS. |
| FRCM | CAV Field IF In | 50 MHz/+0 dBm cavity field reference |
| FRCM | CAV FWD RF In | Forward power into splitter – 805.0 MHz/+10 dBm max |
| FRCM | CAV RFL RF In | Reflected power from splitter – 805.0 MHz/+10 dBm max |
| FRCM | RF Out | 805.0 MHz feed to transmitter |

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| HPM | RF_PERMIT In | Input from MPS or Vacuum System – Opto-isolated Rx at HPM. HIGH = OK |
| HPM | RF_FAULT* Out | Output to MPS – Opto-isolated Rx at MPS. HIGH = OK |
| HPM | RF 0 In | Cavity Field Probe – 805.0 MHz/+10 dBm max |
| HPM | RF 1 In | Circulator Load Forward Power – 805.0 MHz/+10 dBm max |
| HPM | RF 2 In | Splitter Load Forward Power – 805.0 MHz/+10 dBm max |
| HPM | RF 3 In | Cavity Feed Reflected Power 1 – 805.0 MHz/+10 dBm max |
| HPM | RF 4 In | Cavity Feed Reflected Power 2 – 805.0 MHz/+10 dBm max |
| HPM | RF 5 In | Instrumentation Channel 1 – 805.0 MHz/+10 dBm max |
| HPM | RF 6 In | Instrumentation Channel 2 – 805.0 MHz/+10 dBm max |
| HPM | BB 7 In | Phase detector Input - ± 100 mV baseband |
| HPM | FOARC 00 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 01 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 02 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 03 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 04 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 05 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 06 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 07 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 08 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 09 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 10 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| REF | TC 1 In | Input from Thermocouple 1 in the reference line in the tunnel. |
| REF | TC 2 In | Input from Thermocouple 2 in the reference line in the tunnel. |
| REF | CNTL 1 Out | 115VAC out to heater strip 1 in the reference line in the tunnel. |
| REF | CNTL 2 Out | 115VAC out to heater strip 2 in the reference line in the tunnel. |
| REF | RS-485 COM | Bi-directional RS-485 communications between REF heater controller and EPICS. |

RFCS CCL Cables

| Signal Description – RFCS CCL Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Cavity field to mixer RF port | RF | Heliax | Tunnel | |
| Tunnel reference line to mixer LO port | RF-50MHz | Heliax | Tunnel | |
| Cavity field IF from mixer to RFCS (FRCM) | 50 MHz | Heliax | Tunnel to Gallery | |
| Cavity field pickup loops for instrumentation | RF | Heliax | Tunnel to Gallery | Yes 2 |
| Pickup loop for cavity arc detection (HPPS)<br>Cavity to RFCS | RF | Heliax | Tunnel to Gallery | |
| D/C on W/G feed back to RFCS (HPPS) (for cavity arc detection) | RF | Heliax | Tunnel to Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| Pickup-loop from upstream cavity to mixer for cavity to cavity phase | RF | Coax (Times | | |

| Signal Description – RFCS CCL Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| detection | | LMR 100?) | | |
| Pickup-loop from downstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Signal from mixer used as a phase detector. Mixer to HPPS | Quasi-DC | Coax (Times LMR 100?) | | |
| Output to "Beam Off" Fast Protect system | TTL | TBD | Gallery | |
| Input from Machine Protect System – "OK for RF on" | TTL | TBD | Gallery | |
| Fiber optic arc detector signal from HPRF rack (where arc detectors are located). Contains info about arc in waveguide. n=11 | TTL | TBD | Gallery | yes |

### *5.3.4. RFCS SRF*

SRF External Inputs/Outputs

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| CDM | $T_0$ In | $T_0$ signal from Timing Module to CDM - **TBD** |
| CDM | 755 LO In | LO Signal from Reference system in tunnel -- 755.0 MHz/+10 dBm |
| CDM | 2.5 MHz In | 2.5 MHz / +10 dBm from Reference Rack |
| FRCM | Diagnostic In | Beam feed forward input from Diagnostic Group Rack – **TBD** |
| FRCM | FO I/Q Out | Pair of Digital FO data links to Control Room patch panel – **TBD** |
| FRCM | RCCS Out | ±5V error signal to RFCS RCCS Differential amp box located at RCCS rack. Output of Differential amp is 0-10V to RCCS. |
| FRCM | CAV Field IF In | 50 MHz/+0 dBm cavity field reference |
| FRCM | CAV FWD RF In | Forward power into cavity – 805.0 MHz/+10 dBm max |
| FRCM | CAV RFL RF In | Reflected power from cavity – 805.0 MHz/+10 dBm max |
| FRCM | RF Out | 805.0 MHz feed to transmitter |
| HPM | RF_PERMIT In | Input from MPS or Vacuum System – Opto-isolated Rx at HPM. HIGH = OK |
| HPM | RF_FAULT* Out | Output to MPS – Opto-isolated Rx at MPS. HIGH = OK |
| HPM | RF 0 In | Cavity Field Probe – 805.0 MHz/+10 dBm max |
| HPM | RF 1 In | Circulator Load Forward Power – 805 MHz/+10 dBm max |
| HPM | RF 2 In | Circulator – Cavity Reflected Power – 805.0 MHz/+10 dBm max |
| HPM | RF 3 In | Spare |

| RFCS Subsystem | RFCS Signal | Description |
|---|---|---|
| HPM | RF 4 In | Spare |
| HPM | RF 5 In | Spare |
| HPM | RF 6 In | Spare |
| HPM | BB 7 In | Phase detector Input - ± 100 mV baseband |
| HPM | FOARC 00 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 01 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 02 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| HPM | FOARC 03 In | Input from HPRF System – Opto-isolated Rx at HPM – Connector **TBD** |
| REF | TC 1 In | Input from Thermocouple 1 in the reference line in the tunnel. |
| REF | TC 2 In | Input from Thermocouple 2 in the reference line in the tunnel. |
| REF | CNTL 1 Out | 115VAC out to heater strip 1 in the reference line in the tunnel. |
| REF | CNTL 2 Out | 115VAC out to heater strip 2 in the reference line in the tunnel. |
| REF | RS-485 COM | Bi-directional RS-485 communications between REF heater controller and EPICS. |

RFCS SRF Cables

| Signal Description – RFCS SRF Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| Cavity field to mixer RF port | RF | Heliax | Tunnel | |
| Tunnel reference line to mixer LO port | RF-50MHz | Heliax | Tunnel | |
| Cavity field IF from mixer to RFCS (FRCM) | 50 MHz | Heliax | Tunnel to Gallery | |
| Cavity field pickup loops for instrumentation | RF | Heliax | Tunnel to Gallery | Yes 2 |
| Pickup loop for cavity arc detection (HPPS)<br>Cavity to RFCS | RF | Heliax | Tunnel to Gallery | |
| D/C on W/G feed back to RFCS (HPPS) (for cavity arc detection) | RF | Heliax | Tunnel to Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| D/C on circulator load (to HPPS) | RF | Heliax | Gallery | |
| Pickup-loop from upstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Pickup-loop from downstream cavity to mixer for cavity to cavity phase detection | RF | Coax (Times LMR 100?) | | |
| Signal from mixer used as a phase detector. Mixer to HPPS | Quasi-DC | Coax (Times LMR 100?) | | |
| Output to “Beam Off” Fast Protect system | TTL | TBD | Gallery | |
| Input from Machine Protect System – “OK for RF on” | TTL | TBD | Gallery | |
| Fiber optic arc detector signal from | TTL | TBD | Gallery | yes |

| Signal Description – RFCS SRF Subsystem | Signal Type | Connection Medium | Location | >1? |
|---|---|---|---|---|
| HPRF rack (where arc detectors are located). Contains info about arc in waveguide. n=5 | | | | |

### *5.3.5. VXIbus Backplane Definition*

| Channel | Name | Source | User | Function |
|---|---|---|---|---|
| ECLTRG00 | 40MHZ | CDM | ALL | 40 MHZ clock (falling edge mark) |
| ECLTRG01 | 10MHZ | CDM | ALL | 10 MHZ clock (falling edge mark sync'd to 40 MHz) |
| LBUS[00..11] | LBUS | | | Event Link Data - **TBD** |
| TTLTRG0* | SAMPLE* | CDM | ALL | Synchronous data sample strobe. Latch data on falling edge, clear data registers on rising edge. |
| TTLTRG1* | | | | Spare |
| TTLTRG2* | | | | Spare |
| TTLTRG3* | RF_GATE* | CDM | ALL | LOW when RF is ON / HIGH when OFF. [See Note] |
| TTLTRG4* | $T_0$ | CDM | ALL | $T_0$ sync pulse from master timing system. Falling edge is fiducial. [See Note] |
| TTLTRG5* | FAULT_L* | ALL | HPM | RF fault in LEFT half of crate. (Klystron A).<br>LOW = FAULT (RF off) |
| TTLTRG6* | RF_FAULT* | HPM | MPS FRCM | Tell MPS to turn off beam during faults.<br>LOW = FAULT (Beam off) |
| TTLTRG7* | FAULT_R* | ALL | HPM | RF fault in RIGHT half of crate. (Klystron B).<br>LOW = FAULT (RF off) |

*Table Notes:*

1. The HPM has one input (RF_PERMIT) and one output (RF_FAULT*) to the machine protection system (MPS). If RF_PERMIT goes low, the HPM pulls TTLTRG5*, TTLTRG6* and TTLTRG7* low on the backplane. Likewise, if either TTLTRG5* or TTLTRG6* are asserted on the backplane, the HPM pulls RF_FAULT* output low to notify MPS of the fault.
2. Timing between TTLTRG3* and TTLTRG4* is **TBD**.